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SIMULATORS AND ENHANCED TRAINING

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13. ABSTRACT *(Maximum 200 words)*

In this paper we discuss simulators and training devices in the overall context of training and show how their cost-effectiveness might be quantified. The paper discusses current DoD policies on training and simulation and briefly describes existing practice. The paper summarizes selected cost-effectiveness analyses from research literature comparing simulators and training devices with actual equipment and operations, reinterprets some of the data behind these analyses, and collects additional cost information. The results of this examination suggest that all major existing training options have value and that large changes in the simulator mix should not be made suddenly. However, on the margin, additional simulators and training devices are affordable, and in many situations appear to be cost-effective relative to actual equipment and operations. The analyses are not conclusive due to incomplete data. Recommendations are made on how to develop additional information.

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PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Office of the Assistant Secretary of Defense (Force Management and Personnel) (OASD (FM&P)), under contract MDA 903 89 C 0003, Task Order T-L7-798, issued 15 March 1990. The objective of the task was to identify promising approaches to maintaining strong military manpower capability during a period of declining budgets and force levels. This is one of seven papers to be published. Each paper covers a specific area of military manpower management: the proper experience mix, personnel movement, the timing of training, lateral entry, the link between career progression and assumption of management responsibilities, individual training methods, and increased use of simulators for training. This paper addresses the use of simulators for training.

This work was reviewed by Waynard C. Devers, J. D. Fletcher, and William T. Mayfield of IDA.

EXECUTIVE SUMMARY

This summary has three sections. The first summarizes the tasking that this paper addresses. The second section outlines the organization of the paper, and the third section summarizes the main body of the paper.

INTRODUCTION

The issue of whether the increased use of individual and networked simulators and training devices for training should be undertaken was chosen for study because of a perception that: (a) in some cases increased use of simulator-based training is feasible or more cost-effective than current training practices, and (b) there is increased pressure on training budgets. The purpose of this paper is to: (a) provide a framework to assess the cost-effectiveness of individual and networked simulators and training devices to provide peacetime training for warfighting skills, (b) report or perform preliminary analyses within this framework, and (c) draw conclusions from these analyses, for either actions to take or information to gather.

Keeping the scope of this paper to simulators is difficult. Most peacetime military activity can be looked on as preparation for warfighting, and much of that preparation is simulation in a general sense. Additionally, technological and operational trends are blurring distinctions and allowing interoperability between simulators, other training devices, war games, equipment stimulators, and training on instrumented and uninstrumented ranges. We believe we have maintained these distinctions where appropriate, but will not hesitate to use "simulators" to mean several of these categories, particularly "simulators and training devices."

OUTLINE

This paper is divided into an introduction and four substantive sections. The first two substantive sections provide background. The first of these, Basic Issues, describes a taxonomy for viewing training, a brief description of simulation in training and an approach to measuring the cost-effectiveness of various methods of training. The second, Current Policies and Practices, discusses existing Department of Defense (DoD) Directives as they apply to simulation in training. Additionally, it describes some of the simulations and simulators that are currently used to train warfighting capability and the DoD organizations that monitor their use.

The Data and Analyses section has three purposes. The first is to present information on current expenditures for training expenditures related to operating tempo (OPTEMPO). The second is to review literature on simulator cost and effectiveness. The third is to attempt cost-effectiveness comparisons: (a) of OPTEMPO flight hours versus simulator time, and (b) of Simulator Network (SIMNET)-like facilities with exercises at both the National Training Center (NTC) and home-station training ranges and maneuver areas. The latter comparison cannot be made because all the necessary cost and effectiveness data are not available. However, several useful inferences can be drawn about policy options and further research.

The Conclusions and Recommendations section summarizes key conclusions from our research and discusses actions to take and information to gather that could further improve future training decisions.

SUMMARY

Basic Issues

There is sufficient evidence, both anecdotal and quantifiable, to indicate that combat experience is the best trainer of combat skills. Simulations have long been used as peacetime substitutes for combat operations. In many cases, this has been done because training through actual exercises could not be done. In other cases, the reason was that simulations were more cost-effective. Individual and networked simulators and training devices are one simulation approach.

We now have both (a) the technological capability to create a continuum of training options based more heavily on computer simulations and (b) conceptually sound methods to measure the cost-effectiveness of these approaches. These technological capabilities include better individual simulators and networked simulators, such as SIMNET, for collective training. Replicating existing capabilities for individual or networked computer simulators, as well as other computer simulations, is becoming significantly less expensive due to reductions of 25% per year in the price of the computer equipment that is often used in their construction. Additional capabilities are being developed to enhance training or to support other requirements such as mission rehearsal.

Both qualitative and quantitative cost-effectiveness comparisons can be made between different simulations and between simulations and actual operations. Qualitative comparisons usually focus on the realism of various options as evaluated by the participants. Quantitative comparisons use methods such as training Transfer Effectiveness Ratios (TERs). A TER is the ratio of two training options' contribution to meeting some training criterion. This TER is then compared with the ratio of the costs of the training options. The quantitative comparison follows the approach of microeconomic theory to arriving at the most efficient combination of inputs (time spent training on both simulators and actual equipment) to produce a given output (individual and collective readiness or warfighting capability).

Current Policies and Practices

DoD Directive 1322.18, Military Training, and DoD Directive 1430.13, Training Simulators and Devices, contain basic guidance for using simulators in training. They direct that there be a systems approach to training and that simulators and training devices should be subject to a cost-benefit analysis as one alternative in an overall training strategy to optimize the operational readiness of the force.

The primary reason for using simulators is improving readiness, but cost savings due to increased simulator use are an important secondary consideration. Guidance for collective, networked simulators is not explicit, though vigorous programs in training technology research are suggested.

There are many training options that provide simulations of actual combat. These include a variety of exercises (REFORGER, NTC, field exercises on home-station training areas), simulators (SIMNET, individual platform simulators) and higher echelon war games. These options provide environments that train through integrating skills and knowledge gained previously, offer different degrees of realism and effectiveness, and have different costs.

Data and Analyses

We develop a rough estimate of the cost of OPTEMPO, one of the primary ways collective training is provided. In FY 1991 dollars, for DoD, this estimate is $21 billion, including $12 billion of flight OPTEMPO, $8 billion of ship OPTEMPO, and $1 billion for Army vehicle OPTEMPO. Simulations can leverage these expenditures to increase their efficiency and impact on readiness and effectiveness.

The Analyses subsection presents two types of comparisons of the costs and effectiveness of several of the training options. The first shows the tradeoff of flying-hour OPTEMPO for possible increases in simulator time. The second attempts to compare the costs and effectiveness of SIMNET with actual exercises at field training locations. The data that underlie the first comparison are mainly from a literature review of maintenance and flight simulator costs and effectiveness, and the second, from studies comparing SIMNET and field exercises.

The purpose of these examples is to highlight key information that is needed to develop cost-effectiveness analyses. The quality of the information provided is not sufficient to provide detailed policy guidance, but does appear to offer some preliminary insights.

OPTEMPO Versus Flight Simulators

Prior studies of the cost of training in actual equipment versus flight simulators in all services show that representative simulator operating costs vary in a wide range around 10% of actual equipment operating costs per hour trained. Acquisition costs for simulators also have large variation, and can be as high as actual equipment costs. Fragmentary information on break-even costs suggest that representative simulators can be amortized in approximately two years. The conclusions drawn from these studies are that the relative cost of simulators is 10% of actual equipment when both actual equipment and simulators are already in the inventory, but closer to 33% when simulators must be both acquired and maintained. Recent information on selected systems are at least as low as these estimates.

With respect to the relative effectiveness of simulators and actual equipment, TER comparisons from the literature suggest that the majority (59%) of tasks trained have TERs greater than 0.33, and 94% have TERs greater than 0.1.

Combining this cost and effectiveness information means that individuals can be cost-effectively trained on most tasks using simulators at current ratios of simulator to actual equipment training. In addition, there are tasks that, for safety, environmental, or security reasons, are not currently trained using actual equipment. Many of these tasks can be trained using simulators.

Based on this evidence regarding relative training costs and effectiveness, it would not be overly risky to transfer a small proportion (perhaps 5%) of the flying-hour budget to simulator acquisition and operation. Some additional funding might be needed initially to maintain readiness while simulators are acquired. After a period of one to two years of investing these transferred funds, the results could be used to either cost-effectively increase overall readiness or to maintain a given level of readiness at a lower overall cost.

The data warn against considering large transfers of this type without further analysis. The savings from a 5% decrease in flying hours could be used to generate a 15% to 50% percent increase in simulator hours (based on the 10% to 33% cost range discussed above). The effects of those sorts of increases on TERs should be understood before still greater simulator utilization is undertaken, and we believe experiments should be undertaken to develop this understanding.

SIMNET, NTC, and Home-Station Exercises

We found effectiveness comparisons between SIMNET and home-station field exercises and a comparison of the incremental effect of home-station field exercises on NTC performance. These comparisons are insufficient to support conclusive findings.

Analysis of an effectiveness comparison between SIMNET and home-station field training supports the hypothesis that SIMNET is extremely effective in increasing performance for SIMNET-trainable tasks relative to standard field training.

Tradeoff analyses were done between vehicle OPTEMPO and networked simulator costs. They showed that investment now in SIMNET-like facilities could be repaid once the facilities were fielded by a decrease of 8%-14% of OPTEMPO. The 14% figure is similar to an Army estimate of the vehicle mileage that would be substituted for by the SIMNET follow-on, the Close Combat Tactical Trainer (CCTT).

CONCLUSIONS AND RECOMMENDATIONS

This section of the paper briefly reviews the conclusions from the data and analyses section, and then presents recommendations for further research. The purpose of the research is to supply decision makers with further information on the cost-effectiveness of incremental changes in simulator use.

Individual Simulators for Training

The cost-effectiveness of simulators for individual operator and maintainer training has been studied, and there is a body of literature in this area. However, this issue needs additional experimental research for the following reasons:

- The cost of simulators is heavily based on digital electronic technology, and that cost will continue to fall in the future.
- Political and environmental changes are likely to further constrain the use of actual equipment and field exercises versus operator and maintainer simulators.

- Research indicates that the marginal impact of additional simulator use on performance can change dramatically depending on the amount of simulator training.

Networked Simulators for Collective Training

Each training approach: home-station field training, networked simulation, and NTC, is cost-effective in training some tasks. Only extreme changes in the cost or effectiveness of a given option would alter this. However, if the findings summarized previously are reinforced by the experiments suggested here, SIMNET-like facilities should be developed and substituted for some home-station field exercises, and the distribution of training tasks among these locations should be re-examined in order to better utilize the strengths of each.

Experiments should be developed to examine the relative contributions to combat effectiveness of NTC, field exercise, and networked simulator facilities. Existing data do not fully support the sort of analyses that are needed. Without additional information, resource allocation decisions will continue to be made without adequate knowledge of their implications. Where possible, these analyses should generate data on the effects of incremental changes in simulator and actual exercise training so that policy makers are better informed about the cost-effectiveness tradeoffs.

In addition, networked simulator cost-effectiveness issues could be addressed empirically by extending recent analysis of the effects of home-station field exercise activity on NTC performance to include SIMNET activity. By including both home-station field exercises and SIMNET-like facilities in analysis of NTC performance, we should be able to better understand the process of producing readiness or warfighting capability through all collective training options.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

This report addresses the issue of whether increased use of simulators and training devices for training military personnel is cost-effective. Information is included on simulators used by both individuals and crews, recent advances in networked simulators, and wargaming technologies. Individual and crew simulators provide individual operator and maintainer training. Networked simulators can be used to provide collective "warfighting" training for relevant Department of Defense (DoD) elements such as units in (a) the individual military services, (b) joint commands consisting of units from two or more individual services, and (c) combined commands that include allied forces as well as U.S. joint commands.

The analysis is presented in four sections, each of which addresses specific questions, as follows:

- *Basic Issues.* Is there a mismatch between the measured cost-effectiveness of various approaches to "warfighting" training and their actual application? To what extent are changing costs (e.g., the fall in the price of digital electronics used in simulations, simulators, and training devices, and the rise in the cost of actual equipment) and emerging technologies (e.g., the networking of simulators and other training options) likely to change the cost-effective balance of training options? How should we measure this mismatch and these trends?
- *Current Policies and Current Practices.* What are the operative current policy documents? To what extent do they address the basic issues? What are the current practices in the uses of simulators and training devices for training?
- *Data and Analyses.* What sort of data are available to allow us to understand the effectiveness and cost of various training options? What evidence is there that technology can be used (or better used) to improve the current practices? Can we use this evidence to generate first-order cost-effectiveness analyses of simulations compared with other training options?
- *Conclusions and Recommendations.* What conclusions can be drawn from the data and analyses? How should training practice be changed on the basis of existing evidence? In what areas might further analyses—including further original or secondary research efforts—be warranted? If such further analyses or research and development were conducted and successfully completed, what differences would they make, and what would the differences be worth?

Keeping the scope of this paper to individual and networked simulators and training devices is difficult. Most peacetime military activity can be looked on as preparation for warfighting, and much of that preparation is simulation in a general sense. Additionally, technological and operational realities are blurring distinctions and allowing interoperability among simulators, war games and warfare models, equipment stimulators, instrumented and uninstrumented ranges, and even mission rehearsal The latter point means that, throughout this paper, we will tend to use the term "simulators" to represent the continuum of training equipment options that stops short of actual operations.

II. BASIC ISSUES

This section provides a brief statement of the overarching goal of training and a taxonomy that describes the current organization/location approach to delivering this training. Then, because of this paper's focus on simulation as a training method, examples of the history and effectiveness of individual and collective warfighting simulations are provided.

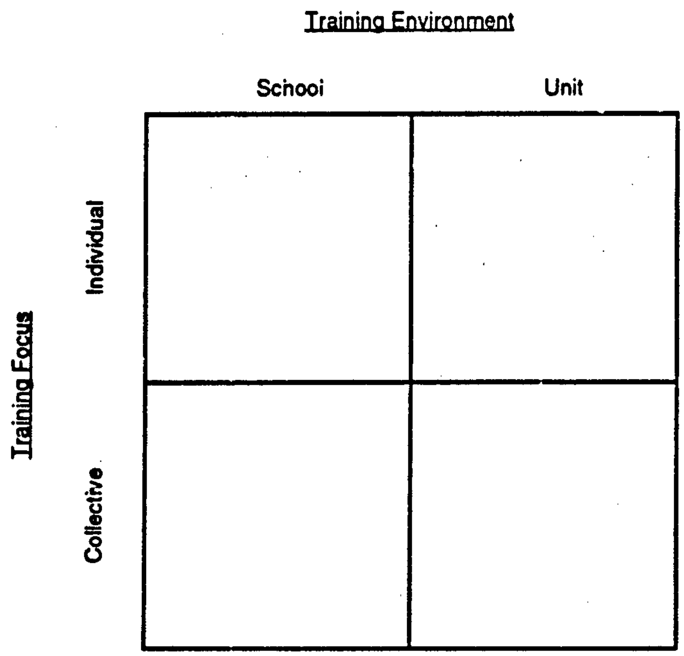
A. GOAL OF TRAINING

The goal of training is to create a military that is "capable of carrying out national security missions in peace and war as called upon" ([1], p. 8). In order to accomplish this goal in a cost-effective manner—where cost includes lives as well as dollars—individuals must have mastered the skills and knowledge to perform the tasks that make up their individual jobs, and these individuals must be trained as part of collectives (from fire teams and air crews to combined commands). Differences between individual and collective training requirements result in different design and delivery approaches to training.

B. A TRAINING TAXONOMY

Military training can be categorized into a two-by-two matrix as shown in Figure 1. This taxonomy divides training by environment (school versus unit) and by focus (individual versus collective). For each cell in the matrix, we will discuss whether: (a) training received is well-quantified or not; (b) it is easy or difficult to quantitatively describe training requirements and compare training effectiveness; and (c) simulations and simulators are or could be used.

Most of the *formally delivered* military training to which DoD policies apply is conducted in military schools or institutional environments and focuses on the individual soldier, sailor, marine, or airman. Much of it is technical or specialty training designed to provide individual trainees with the knowledge and skill essential to the performance of their assigned jobs. This sort of training is typically associated with fixed facilities, faculties, curricula, and procedures that are essentially similar to those of civilian school systems.[1]



Note: Adapted from Reference [2].

Figure 1. A Taxonomy of Military Training

Very little collective training is provided in schools, and most of that is more properly classified as professional education, e.g., senior service and defense colleges and universities. Such professional education is outside the scope of this paper, and is not considered further.

Unlike the facilities and equipment used for individual training in schools, the facilities and equipment in units may be poorly suited to the desired collective training. The unit's leaders have to manage the training with a "faculty" drawn from the unit's assigned personnel. Some of these personnel are not much more experienced in the subject matter than are their students, and most have not been trained in instructional techniques. The curriculum is constantly changing and is complicated by the availability of resources such as ranges, and on-going requirements for individual on-the-job training delivered by first-

1 For additional analysis of the cost-effectiveness of current individual training delivery systems, see Reference [3].

line supervisors—training that is largely unstructured and unevaluated, and often with only poor records of skill acquisition and maintenance. Actual operations enhance some training activities, but operational priorities further fragment others.

While individual training, particularly at school, is essential to give personnel the ability to perform their jobs, most of the needed "warfighting" training can be met only by training of the "collectives"—the crews, groups, teams, or units (CGTUs)—that are combined to constitute a military unit, e.g., an Army or Marine platoon, company, or battalion, a Navy ship, battle group, or battle force, and an Air Force (or Army, Navy, or Marine Air) flight, squadron, or wing. Such *collective unit training* is directed towards the development of teamwork among the individuals within a CGTU—and among the CGTUs within a larger military unit—who are to perform (often stressful) tasks and missions in common. It is exactly the type of training central to the preparation of a military unit for battle.

Collective unit training has been less intensively studied than schoolhouse training (see Reference [4]). This is partially because it is often difficult to determine whether such training is actually occurring; that is, whether combat-relevant skills are being correctly learned, executed, and maintained. Because of this, it is difficult to determine what resources were used for training. Also, it is difficult to develop meaningful measures of effectiveness (MOEs) for many collective unit training activities when the immediate feedback of casualties suffered and inflicted are unavailable. In summary, measuring the performance of many different collectives networked together has been extremely difficult.

This comparison highlights the difficulties in providing warfighting training in general, and collective unit warfighting training in particular. One approach to overcoming them is to simulate a combat environment in order to train part of what can be learned through actual combat.

C. HISTORY OF SIMULATING WARFARE AS TRAINING

The concept of developing a "practice war" as a method of training a force for actual combat may be as old as war itself. Models, simulations, and war games to represent warfare are said to predate recorded history. Indeed, the use of elementary forms, such as iconic figures, sand tables, chess-like game boards, and field exercises or other operations, has been documented from pre-Roman times. However, there appears to have been little formalization of the procedures for more abstract simulations until professional military colleges and schools were established in the 18th century. The appearance of the German "Kriegspiel" in 1811 marked the beginning of the use of large and complex manual games that employed maps and rules based on actual operational doctrine. From the Franco-Prussian War throughout World War II, every major military power relied heavily on the use of institutionalized manual war games for force planning, training, doctrine development, and evaluation of war plans. Since then, the manual games have been largely replaced by computer-based models, simulations and war games. By 1986, the Joint Chiefs of Staff's "Catalog of War Gaming and Military Simulation Models" listed approximately 600 different active simulations [5], up from 360 in 1982.

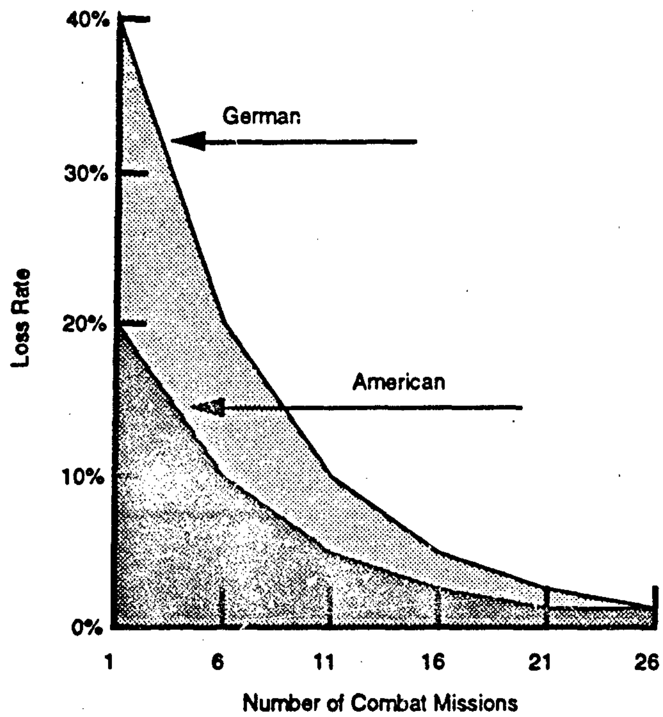
D. EFFECTIVENESS OF EXERCISES IN TRAINING FOR COMBAT

This section presents evidence that there are vast differences in the combat performance of individuals and collectives, that combat experience is a primary determinant of combat performance, and that simulating combat can partially substitute for actual combat.

There is some evidence, and a considerable number of testimonials from warriors and military historians, of vast differences in the battle effectiveness of commanders and their units—much of these attributable to differences in experience and collective training. Naval commanders and historians know of "good ships" and "poor ships," often representing essentially identical hardware in ships of the same class. Army commanders and historians know of "good divisions" and "poor divisions," identically equipped and often fighting side-by-side.

Data are available to support these assumptions. For example, one NATO-sponsored study of World War II German U-boat commanders found that 32.9% failed to engage any targets, and 13.1% failed to hit any targets they found. Thus, 46% were ineffective. On the other hand, the best 10% of the commanders sank 45% of the Allied ships sunk by submarines [6].

Another example is drawn from the World War II air-battle experiences of the German and American forces in the European theater. This is shown by the air-combat loss rates represented in Figure 2. The German pilots experienced nearly 40% first-mission losses, whereas the American first-mission loss rate was half that, or about 20%. The figure shows essentially a five-mission advantage for the American pilots relative to the German pilots. This advantage has been attributed to the differences in their training. The Germans were short of fuel, and although they trained their pilots well to fly the aircraft, they did not have fuel to "waste" on the additional training of air-combat maneuvering skills [2 and 7].



Note: Adapted from Reference [6].

Figure 2. Air Combat Loss Rates in World War II

Another example of differences that result from training through combat simulation is shown in the exchange ratios for the Vietnam air war that are shown in Table 1. The table shows aircraft exchange ratios from two 4-year time periods, where the omitted year had no losses. The exchange ratios shown are an overall ratio, followed by ratios for the U.S. Air Force (USAF) and the U.S. Navy (USN). The data to construct these ratios are then presented.

The major difference in the data is the 5:1 improvement in the USN exchange ratio for the later period. The difference between these periods is the establishment of the Top Gun Fighter Weapons School, a school that used engagement simulation (mock combat) and intensive after-action reviews of the simulated combat to train pilots [2].

Table 1. :hange Ratios in the Vietnam Air War

Category	Time Period 1965-1968	1970-1973
Overall Exchange Ratio	2.29	2.74
USAF Exchange Ratio	2.25	2.00
USN Exchange Ratio	2.42	12.50
Enemy Losses	110	74
US Losses	48	27
USAF Kills	81	49
USAF Losses	36	25
USN Kills	29	25
USN Losses	12	2

ource: Reference [2].

E. OPERATIONS, EXERCISES, SIMULATORS, AND COST-EFFECTIVENESS

This section discusses different ways that simulators can be used to augment exercises or operations as warfare simulations. It then offers a conceptual approach to analyzing the cost-effectiveness of these simulators. Finally, several other issues that affect the cost-effectiveness of simulators are discussed.

Simulations may allow training through representation of a type of actual operation or exercise that is effectively precluded by political, safety, security or budget constraints, or it may allow a type of training that substitutes for a particular operation. Simulations may substitute directly (a particular task or maneuver can be trained almost entirely through simulation) or indirectly (training some tasks through simulation leaves additional operating time for training actual tasks that are not easily learned through simulation). In addition, using simulators for direct mission rehearsal for specific operations is discussed in section II.E.5, Other Factors that Affect Simulator Cost-Effectiveness.

1. Training for What Could Otherwise Not Be Done

One example of actual training that is precluded by political constraints is to practice hostile activities on a potential adversary's territory to understand the unique characteristics of the operation based on that territory. An alternative approach is to conduct actual exercises over similar terrain similar to that of the adversary and to which access is available. Another is to use a simulator that can project a realistic representation of the area to be attacked, such as simulated bombing runs on Moscow or Baghdad.

An example of allied or domestic political constraints would be the unwillingness to have large, intrusive exercises occur frequently over particular territory. Specific examples of this constraint might include the Federal Republic of Germany's reluctance to allow frequent NATO exercises over its territory. Another example is that even if Washington, D.C., were a perfect match for a major potential target for low-level B-52 attacks, political considerations would make it inappropriate to practice such attacks.

Simulators could be substituted for either operational or maintenance training when the activities in question are too dangerous or destructive to be trained on actual equipment, or where frequent use of the equipment would offer the potential for security compromises with respect to operating characteristics or procedures.

Determining the cost-effectiveness of operational training has been difficult because even when the training was possible, both the costs and benefits were difficult to quantify. However, recently developed networked simulator technologies make some of these simulations possible, and others allow the costs and benefits of some simulations to be better measured. Specifics of this approach will be discussed in the following sections.

2. Simulators as Substitutes for Actual Equipment

Even when actual equipment can be used in the field for collective training, there may be reasons to use simulators instead. Training using simulators allow for small incremental changes to the balance of simulation and actual operation. For example, if the tasks of a particular platform operator can be separately identified and trained, then tasks where simulated training is particularly cost-effective could be trained almost exclusively through simulation. This would result in either a budgetary savings, or the opportunity to undertake additional training on actual equipment to train difficult tasks that are not well simulated.

An additional condition that can favor simulation versus actual equipment training is range availability. For example, according to the Government Accounting Office (GAO), one conclusion of a Navy training assessment was that "there are limited numbers of ranges, most of which lack the ability to provide a realistic threat environment for training" ([8], p. 15). Limitations on ranges may result from demographic changes (surrounding areas that were once uninhabited are now populated) or technological changes (the tactical reach of new weapon systems is becoming greater). In addition, this GAO report cites earlier GAO work that found shortages in military training airspace "decreased aircrew training effectiveness, caused some units to deploy significant distances to areas where airspace was available, and caused some units to obtain waivers for some training requirements to avoid reporting degraded readiness" ([8], p.16). Similar comments were made by Army helicopter training instructors, who pointed out that airspace and budgetary restrictions mean that the vase majority of training that pilots receive in the employment of certain advanced missiles is through simulator use [9].

Problems such as range availability can either be modeled as additional constraints, or through a difficult-to-quantify increase in the cost of training with actual equipment. In any case, this problem suggests that employing more simulation has the potential to be a cost-effective strategy.

3. Cost-Effectiveness of Simulations

This section provides both a qualitative and a quantitative method for assessing the cost-effectiveness of simulations.

a. Qualitative Issues

A qualitative, first-order approximation of the effectiveness of a simulator used for training is the realism or fidelity with which a simulator reproduces actual equipment and its operation. In most cases, the more realistic is a simulation of the training-relevant aspects, the better it trains, and the more it costs.

However, this mental model must be used carefully for two reasons. The first reason is that, as opposed to actual operations with real equipment, it is possible to build simulators to train specific tasks. For example, pre-flight cockpit checks can be trained in a simulator without expensive subsystems such as terrain display, six-axis motion, or the airframe, engine(s), and avionics of an actual airplane. Therefore, it is important to be clear on what aspects of actual equipment or operations must be realistic for the particular tasks to be trained.

Secondly, the relation of cost to realism is neither linear nor the same for different tasks. Figure 3 presents several possible relationships. Line A might represent the realism-cost relationship for the pre-flight cockpit checks described above, or for a part-task maintenance simulator. Curve B represents the concept that much of the realism in a given simulation can be achieved with relatively little cost, but that approaching perfect fidelity becomes expensive. An example of this is the often voiced subjective assessment that SIMNET achieves 60% of the fidelity or realism of real equipment at 10% of the cost. Curve C might represent training flying tasks where realistic visual and/or motion cues are needed such that the simulator must have the (expensive) equipment needed to provide these cues. For an example of the effectiveness change suggested by discontinuous curves similar to C, see Reference [10].

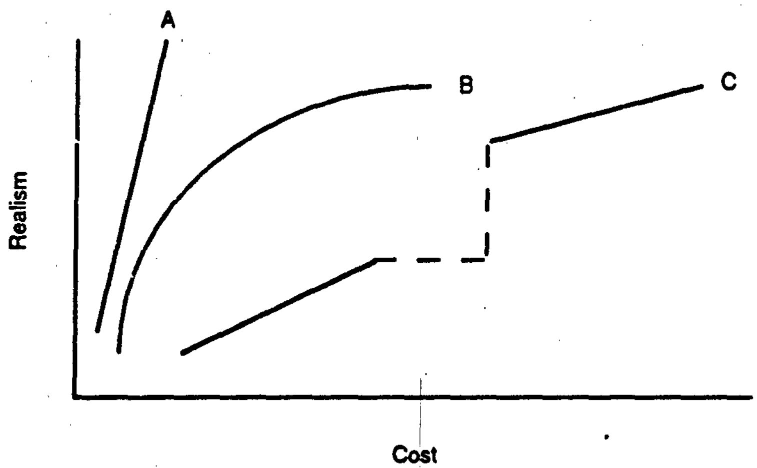


Figure 3. Simulator Cost Versus Realism

This qualitative approach has been criticized and refined in several different ways.[2] It has been stylized as "objective reality," the degree to which the simulator replicates aircraft states and conditions, and contrasted with "perceptual fidelity," the degree to which the trainee perceives the simulator to duplicate the aircraft. Another concept is "error fidelity," which argues that if the errors made in the simulator have the same effects on aircraft performance, and the errors are made in the same way and as frequently as in an actual aircraft, then the simulator will be a better trainer. The literature has generated the following definition of fidelity: "Simulator fidelity is the degree to which characteristics of perceivable states induce correct psychomotor and cognitive control strategy for a given task and environment" [12].

In many ways, the perceptual, error, and simulator definitions above may be construed as better defined, necessary conditions that are not quite as restrictive as the less well-defined, presumably sufficient condition of realism suggested at the start of this section. To some extent, these words are different ways of discussing the concepts represented in Figure 3.

Another way of highlighting this issue is to say that the real question is not high or low fidelity, but what fidelity is needed to satisfy what training objective. In fact, in certain

2 This discussion draws on Reference [11] and the works cited there.

instances the assumption that greater fidelity means better training may not always be correct. For example, in a simulator, certain meaningful cues for a particular task could be temporarily enhanced and distracting cues suppressed to facilitate training. This would allow the trainee to more rapidly identify the important elements of particular tasks. As the trainee became familiar with the needed response, the intensity of the cues could be changed.

b. Quantitative Issues

A well-known and frequently used quantitative method for comparing simulated versus actual operation is the so-called training Transfer Effectiveness Ratio (TER). The TER was described in the training literature [13 and 14]. It is a ratio of actual equipment training time saved as a function of time spent training on a simulation. An algebraic representation of this ratio is $(A_{wo} - A_w)/S$, where A_{wo} is the training time in the actual equipment or situation without (wo) use of a simulator, A_w is the actual time after (with (w)) simulator training, and S is the (non-zero) time spent in the simulator. This ratio can be used for total or cumulative time spent in simulators and actual equipment, or for incremental changes in simulator time that result in incremental changes in actual equipment. Large values of this ratio indicate that simulations train relatively well in comparison to operating actual equipment, and small values indicate that simulations train poorly relative to actual equipment. There is also empirical evidence that this ratio declines as the value of S increases, e.g., Reference [15].

When defined as incremental improvements in capability, the TER has an interpretation similar to the ratio of marginal products in the optimality condition for cost-effective use of inputs in a production process, $(MP_S/MP_A) = (P_S/P_A)$, where MP is marginal product and P is price, and the subscripts S and A are simulator and actual equipment.[3] Therefore, many of the standard results of microeconomic theory can be applied to policy decisions on how much to train using operations and how much to train using simulation. For example, simulators should be used to train tasks for which the TER is greater than the ratio of the price of simulator training to the price of actual equipment training.

3 An incremental change in simulator usage (ΔS) yields a change in the actual equipment time needed to obtain equal proficiency $[\Delta(A_{wo} - A_w)]$. ΔS costs P_S per unit, so the cost incurred is $\Delta S \times P_S$, and $\Delta(A_{wo} - A_w)$ costs P_A, so the cost that could be avoided is $\Delta(A_{wo} - A_w) \times P_A$. Simulators and training devices should be used as long as the cost incurred to attain equal proficiency is less than the cost avoided, or up to the point where the two costs are equal, hence to the point where $\Delta S \times P_S = \Delta(A_{wo} - A_w) \times P_A$. Rearranging terms yields $\Delta(A_{wo} - A_w)/\Delta S = P_S/P_A$ (= MP_S/MP_A).

In following sections, we will present evidence on the cost-effectiveness of individual operator and maintainer simulations, drawn mainly from Orlansky [16] and Fletcher and Orlansky [17]. There is additional evidence suggesting that use of other types of combat mission simulators for training can provide similar results, especially when networked for collective training. For example, during 1987, U.S. Army tank platoons stationed in Europe were trained with a network of SIMNET tank simulators. The skills they gained in the simulator-augmented training transferred positively to the NATO exercise range, and the U.S. Army tankers for the first time in a decade earned the first prize in competition with tankers from other NATO forces [6 and 18].

4. Evaluating Training Options

Clearly, there is a wide range of training options to meet the goal of carrying out national security missions. What combination of simulators and actual equipment (in the case of operator and maintainer training), or networked simulators, actual equipment, and field exercises (in the case of collective training), should be used depends on the relative effectiveness and cost ratios between the various training options. There is no *a priori* reason to assume that any of these options is completely dominated by the others for all trainable tasks. That is, there will be some training tasks that are most cost-effectively undertaken by each training option. Also, there may well be times when temporary resource constraints, e.g., range availability, will preclude some units taking advantage of particular training approaches.[4]

The analytical challenge is to quantify the TERs and costs for alternative training options so that cost-effectiveness tradeoff analyses can be used to help decide which options will be used to train which tasks.[5] Using collective training as an example, we generate readiness through exercises at ranges, maneuver areas, and combat training centers, as well as through the use of training aids, devices, simulators, and simulations. The exercises involve operating equipment, consuming fuel, and expending ordnance. Evaluations of mixes of training options require measuring both the inputs and outputs associated with unit training.

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4 We have eschewed a production-theory-like mathematical treatment because simulators, actual equipment, and collective exercises are themselves a continuum of training options, and because the data on TERs do not currently support such formalism. For standard treatments of these issues, see [19] or [20].

5 For an example of one service perspective on these issues, see [21].

5. Other Factors that Affect Simulator Cost-Effectiveness

There are many other factors that have or will affect the overall cost-effectiveness of simulators. Three are discussed below. They are the falling cost of digital electronic hardware, which has been lowering the cost of a given amount of simulator capability; the increased use of computer software in simulations, which has increased capability but also costs; and the use of training systems as mission rehearsal devices, which may result in cost sharing of simulator development.

a. Digital Electronics

Digital electronics, in particular computers and displays, give some simulators much of their capability. In some cases, they also reflect much of their cost. On average, the constant dollar price of a given amount and type of computer processing power has been falling at the rate of 25% per year[6] (see [22 through 24]). In addition, substitution of microcomputers for larger computers in simulation applications bring one-time savings of one to two orders of magnitude in cost per amount of processing power [25]. There are reasons to believe this decline will continue through this decade [26 and 27].

These price declines have been used to both lower the price and increase the capability of simulations. Also, such price declines indicate that the capabilities of older simulators could be purchased less expensively now. This helps to make the cost-effectiveness results from older studies biased in a conservative direction, that is, against simulations. For a fuller discussion of computer hardware price decreases and their impact on training, see Angier and Fletcher [3].

b. Computer Software

Because computer hardware is cheaper, more of it is used in the production of platforms, weapons systems, and simulators. To control this hardware, and to add additional functionality, more and more complex software is needed. The cost of a given amount of functionality implemented in software has fallen in the range of 5% per year [28 and 29] and it is hoped that this decline can be accelerated [30]. However, the increased requirements for functions that must be implemented through computer software mean that software expenditure will have to rise to accomplish these tasks.[7]

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6 Examples of types of computers are mainframes, minicomputers, and microcomputers. This rate of price decline is a little lower for mainframes, and a little higher for microcomputers.

7 For example, internally generated data at IDA suggest annual growth rates for on-board software for several aircraft in the range of 20% per year.

c. Using Training Systems for Mission Rehearsal

An emerging use for simulators and simulations is as a foundation for mission rehearsal systems. Mission-rehearsal systems are envisioned as particularly valuable in a world where the scenario is not known until just a few days before the operation must commence. They are particularly valuable for training relatively small CGTUs.

An example of this use of simulators is the Special Operations Forces-Air Training System (SOF-ATS). The SOF-ATS is being designed and developed to be a dual-purpose system that can be used for either standard training or rehearsal for specific missions. The system will network seven different aircraft types (two transport aircraft, two gunships, one tanker, and two helicopters) totaling 50 crew positions. A key requirement for this system that is specific to mission rehearsal is the ability to rapidly construct a terrain image of target areas and flight paths to and from the target. The life-cycle cost is projected to be at least $500 million [31].

With respect to training alone, the cost-effectiveness impacts of these dual-use systems are not yet clear. Requirements for mission-rehearsal features may increase the cost of simulators. However, dual-use simulators offer cost sharing of development expenditures, and the additional features may result in better training, even for tasks that were previously trained using simulators.

F. SUMMARY

In summary, training for individuals and collectives occurs in both formal and informal settings. While training of individual skills and knowledge in schools is a necessary part of overall combat readiness, collective unit training is central to the preparation of a military unit for battle. There is sufficient evidence, both anecdotal and quantifiable, to indicate that combat experience is the best trainer of combat skills. Other things equal, combat veterans have out-performed "green" troops in every recorded engagement. Simulations have long been used to augment actual operations, or as a substitute where actual operations or field exercises are not possible, not feasible, or too costly. We now have both the technological capability to create training options based more heavily on computer simulations and conceptually sound methods to measure the cost-effectiveness of these approaches.

III. CURRENT POLICIES AND PRACTICES

This section has two purposes. The first is to describe particular DoD policy-specifying documents regarding simulation and training. The second is to briefly describe some of the ways simulators are used for individual and collective training. These discussions are not designed to be encyclopedic, but to highlight the areas of particular interest for this paper.

A. CURRENT POLICIES

The two principal DoD policy-specifying documents regarding simulation and training are (a) DoD Directive 1322.18, Military Training, dated 9 January 1987 [32], and (b) DoD Directive 1430.13, Training Simulators and Devices, dated 22 August 1986 [33]. The Assistant Secretary of Defense, (Force Management and Personnel) [ASD(FM&P)], is the cognizant and responsible official for both documents.

1. DoD Directive 1322.18, Military Training

DoD Directive 1322.18 defines *military training* as "instruction and applied exercises for the acquisition and retention of skills, knowledge, and attitudes required to accomplish military tasks" ([32], p. 1]). It further defines *collective training* as "instruction and applied exercises that prepare an organizational team (such as a squad, air crew, battalion, or multi-service task force) to accomplish required military tasks as a unit." ([32], p. 1). *Unit training* is "individual or collective training conducted by an operational unit" ([32], p. 1).

The directive goes on to assert a *systems approach to training*, pointing out that all types of military training shall be considered as interdependent parts of an overall training system. It states: "Allocation of resources for the training of military individuals and units, including those of the reserve components, shall be consistent with assigned wartime missions and employment and deployment schedules and related requirements for training" ([32], p. 2). It calls for "vigorous research programs . . . for developing innovative uses of training technology to make military training programs more effective and efficient" ([32], p. 2).

With specific regard to the application of simulation, DoD Directive 1322.18 states ([32], p. 2):

> Simulators and other training devices for weapon systems and equipment shall be developed, procured, distributed, and used when they are capable of effectively and economically supplementing training on the actual equipment. Particular emphasis shall be placed on simulators that provide training that might be limited by safety considerations or constraints on training space, time, or other resources. When deciding on simulation issues, the primary consideration shall be improving the quality of training and consequently the state of readiness. Potential savings in operating and support costs normally shall be an important secondary consideration.

With regard to collective training, which the directive states "shall serve to achieve standards of unit proficiency required to accomplish wartime missions" ([32], p. 5-6), *realism* is mandated as follows:

> Subject to such constraints as safety requirements and limits on space for training, all collective training shall be conducted under conditions and rates of activity closely approximating those that the units being trained may encounter in combat.
>
> (1) When constraints limit the use of realistic training conditions, then simulation and other products of training technology shall be used as applicable to enhance realism.
>
> (2) Collective training, to the degree feasible, shall include electronic warfare activity; nuclear, biological, and chemical defense activity; and the periodic use of opposing forces trained in the tactics of potential adversaries.
>
> (3) All collective training exercises shall emphasize realistic performance of the functions of individual personnel in the exercising units.
>
> (4) Support units shall be integrated into exercises for realistic training in their wartime supporting roles.

For purposes of this paper, it should be noted that the directive calls for joint and combined exercises, but is silent with regard to the possibility of using networks of simulators and war games for such training. It does state that, "To the extent feasible, participation in operational missions shall be used to meet the collective training requirements of the units involved," and that, "All collective training and exercises shall be evaluated against established standards of mission proficiency for identifying and correcting deficiencies" ([32], p. 6).

2. DoD Directive 1430.13, Training Simulators and Devices

DoD Directive 1430.13 is intended to establish "training simulator and device development, acquisition, and utilization policy" and to provide guidance "for establishing Service policy for training simulators and devices" ([33], p. 1) and it emphasizes the integration of simulators and training devices with overall training systems. It establishes

ASD(FM&P) as the principal (and, indeed, the sole) responsible official in the Office of the Secretary of Defense (OSD) in matters bearing on training simulators and devices.

The directive states that policy for simulators and training devices grows out of the general policy of optimizing the operational readiness of the total force. It also states that development and acquisition of simulators and training devices within the services shall be based on each service's training requirements analysis process, and shall include a cost-benefit analysis of alternatives and their potential effects on active, reserve component, and inter-service training.

Under acquisition guidelines, the directive states that alternatives to simulators and training devices as well as alternative simulators and training devices shall be evaluated by the service concerned. This evaluation should include life-cycle costs and benefits, and the flexibility of the system in response to changes in the system to be maintained, and the training location, method, or load. Finally, the directive mandates that commercial practices, equipment, and software may be used when military-specific requirements do not exist.

Like DoD Directive 1322.18, previously discussed, DoD Directive 1430.13 is silent with regard to the use of networks of simulators and war games for training.

3. Summary for Current Policies

The directives develop a taxonomy that allows us to organize our understanding of training location and methods. The directives mandate a systems approach to training, placing all different sorts of training within the overall training system. They also suggest that, particularly for simulators and training devices, the primary consideration shall be improved training quality leading to enhanced readiness; cost issues are described as an important secondary consideration.

The directives are explicit about individual and crew simulators that have a long history in military training. They are not explicit about the use of networked simulators and war games in such training.

B. CURRENT PRACTICES

As indicated earlier, collective (or crew, group, team, and unit—CGTU) training, unlike individual training, is embedded technically and financially in the operating forces. It is, in fact, the operations training of service forces. Depending on the circumstances, what the forces do may be defined as either training or operating. Certainly, with proper feedback and reinforcement, members of the force should be learning while operating.

1. Collective Training—War Simulations Through Field Exercises

The need for advances in collective training has also been recognized by the services (e.g., Reference [2]). But collective training in operational military units, being related so closely to each service's operations and readiness, is regarded as entirely within the domain of the individual service's area of responsibility and authority. Since such training is regarded as fundamentally related to "service-unique" concepts, doctrine, and tactics, each of the services has established its own collective training methods, means, and goals within its operational forces.

For example, having observed a factor-of-five improvement in kill-loss ratio by Navy pilots in the Vietnam Air War subsequent to the Navy's initiation of its air combat maneuvering and engagement training (Top Gun), the Air Force's Tactical Air Command established its version of such training (Red Flag) at Nellis Air Force Base in Nevada "to enable each pilot to experience his first ten 'decisive combats,' and thereby make available to air commanders, on D Day of any future war, the differential between 40% and 5% probability of pilot loss on sortie one, and the significant increase in pilots and aircraft that would be available for sorties two, or three or *n*." ([2], p. 6) The Army's Training and Doctrine Command (TRADOC) sought, and later established, a parallel capability for ground forces ([2], p. 9, 15-16):

> Fortunately, several parallel actions were underway which made it possible ultimately to act affirmatively on TCATA's [i.e., TRADOC Combat Analysis and Test Agency's] recommendation [that laser-aided engagement simulation, supplemented by live fire battle runs, be incorporated into armor training Army-wide]. . . .
>
> . . . modern battle spreads a battalion across a dauntingly large area, and therefore . . . large amounts of land are required to train it for war.
>
> At Fort Irwin, California, the United States Army had enough land to train well at least two battalions of a brigade in modern mobile warfare—1000 square miles of uninhabited land. . . . The National Training Center established there provides an intense experience in moving, shooting, and communicating lasting some three weeks, during which participants fight eight to ten "battles." The training methodology is centered on experiential learning, with emphasis on after-action reviews of each battle, and detailed records of each battle for use by the unit in its subsequent training at home station. The enabling techniques include both TES [i.e., tactical engagement simulation] and live firing, instrumentation of participants which permits recording maneuvers and firing events (real or simulated), and use of a resident Opposing Force (OPFOR), modeled upon a Soviet Motorized Rifle Regiment. Both sides are allowed, within the limits of safety, free maneuver in their operations, and neither is provided any information of the other it does not earn through reconnaissance. But OPFOR has the advantage of knowing the

hostile, complex terrain very well, and it employs Red Army doctrine with ruthless efficiency to expose dependably the slightest tactical ineptitude on the part of a unit in training. Since its opening, over one hundred rotations of the latter have arrived at Fort Irwin to give battle to OPFOR, and only a few would describe their experience as "victorious." Yet in a larger sense, the whole Army has been a winner, for the small defeats in the Mojave Desert have spurred officers, noncommissioned officers, and soldiers to new professional heights.

Understandably, the tactical engagement simulation-based collective training at Fort Irwin is very expensive. Also, an armored or mechanized infantry battalion can expect to train there only once every 18 months or so, a timetable similar to that of an Air Force or Navy squadron training at Red Flag or Top Gun. The benefits of the training are judged by senior military leaders to justify the costs; their major complaint is that there are not sufficient resources (land and air space, as well as budgetary authority) to support several Top Guns, Red Flags, and National Training Centers so that troops could train there more frequently.

2. Collective Training—With Simulator Networking

Starting in the early 1980s, an R&D effort to harness the technology needed for a simulation network that would provide effective and affordable resource for collective training was jointly supported by the Army and the Defense Advanced Research Projects Agency (DARPA).[9]

Simulator Networking (SIMNET) was initiated as a DARPA project on large-scale simulator networking in 1983. It is a proof-of-principle technology demonstration of interactive networking to combine many individuals or crews for man-in-the-loop, real-time, battle-engagement simulation and wargaming. It is the first system to achieve true interactive simulator networking for the collective training of combat skills in military units from mechanized platoons to battalions. SIMNET is also adaptable for training or exercising commanders and staffs at higher echelons, usable in the development of military concepts and doctrine, and suitable for the testing and evaluation of alternative weapon-system concepts prior to acquisition decisions.

In order to undertake frequent training for large engagements, SIMNET and SIMNET follow-ons have been consciously designed to trade some "objective reality" in order to maintain selective fidelity for the features needed to provide effective training. As

9 For a more complete discussion, see Reference [18] or [34].

mentioned earlier, a common subjective assessment is that SIMNET achieved 60% fidelity at 10% of actual equipment costs.

As of 1 January 1990, the available SIMNET components consisted of about 260 ground vehicle and aircraft simulators, communications networks, command posts, and data processing facilities distributed among nine sites--five in the continental United States (CONUS) and four at U.S. Army locations in Europe (USAREUR).[10] A first-order estimate of the cost of this program to this point is $200 million, $50 million in research, development, test and evaluation (RDT&E) and $15 million in procurement funds [35].

SIMNET technology has been transferred to the Army as SIMNET-T, a collective or unit training capability that the Army is planning to extend Army-wide through a large-scale follow-on acquisition program. Specifically, SIMNET was "completed" and transferred to the Army starting in October 1989. Since then, the Army's Project Manager, Training Devices (PM TRADE) has been preparing for procurement of the first several hundred units of the Close Combat Tactical Trainer (CCTT) system, the production follow-on to SIMNET.

This CCTT procurement is to be the first production buy of what is envisioned to be several thousand networkable simulators for armor, mechanized infantry, aviation, and air defense units. When completed, the planned training system will provide a company-level, SIMNET-like training capability at each Army battalion's home base to provide individuals with 20 days of CCTT time per year. In addition, 11 tank and 10 infantry platoon mobile simulators will be used by reserve components. Also, reserve components will be able to use the Army's CCTT facilities on some weekends.

SIMNET-D, another version located at Fort Knox, Kentucky, and AIRNET-D, at Fort Rucker, Alabama, provide a developmental capability that can be reconfigured to simulate new design concepts for evaluation in SIMNET trials. These form the basis of a new joint Army-DARPA initiative to demonstrate Advanced Distributed Simulation Technology (ADST) for use in system development, studies, and analyses [36]. In fact, PM TRADE's acquisition plan, as reported in October 1989, includes provisions for these air and ground-vehicle developmental test beds (AIRNET-D and SIMNET-D) intended to

10 The CONUS sites are at Fort Knox, Kentucky, Fort Benning, Georgia, Fort Rucker, Alabama, Cambridge, Massachusetts, and Washington, D.C. The USAREUR sites are in West Germany at Grafenwöhr, Friedberg, Schweinfurt, and Fulda. The Fort Knox site is currently the largest SIMNET facility with simulators for 44 M1 Abrams tanks, 28 M2/3 Bradley Fighting Vehicles, 2 Scout/Attack Helicopters, 2 Close Air Support Fighter Aircraft, a Battalion Task Force Tactical Operations Center, an Administrative-Logistics Operating Center, and other command and control, artillery and mortar-fire, and close air support control elements—all fully interactive on a local area network.

"provide materiel developers the ability to try out their ideas prior to issuing doctrinal changes or the bending of metal" ([36], p. 14).

Efforts are currently being made to network existing, higher fidelity simulators. Examples of this are the linking of Air Force and Navy flight simulators described in Reference [37], and the linking of different Army helicopter simulators described in Reference [38]. As these simulator networking concepts mature, the capability to link these higher fidelity simulators to SIMNET/AIRNET will likely be developed.

3. Collective Training—Of Higher Echelon and Joint Commands

In 1988, the Defense Science Board (DSB) Task Force on Computer Applications to Training and Wargaming summarized its view on the issue of the collective training of military higher echelons and Joint Commands as follows ([39], p. 1):

> Computer-based, simulated scenarios offer the ***only*** practical and affordable means to improve the training of joint operational commanders, their staffs, and the commanders and staffs who report to them. Such decision makers need the opportunity to exercise their decision skills, to test war plans, and to train to work as a closely coordinated force.
>
> Increasingly, joint training cannot be conducted in the anticipated theater of operations. There are political objections to disruption of civil activity. The cost of an actual exercise at this level is great. Battle simulation offers the only opportunity to practice the use of certain weapon systems, sensors, tactics, and techniques against a skilled adversary.
>
> Today, it is possible to make a substantive improvement to computer-assisted joint training and wargaming. The addition of the Vice Chairman to the Joint Chiefs of Staff, with the delegated responsibility to oversee CINC [i.e., commander-in-chief] operational planning and to serve as spokesman for the CINCs, provides a **management opportunity**. There is also a **technological opportunity**. Driven by the commercial market, computer technology is evolving rapidly and is increasingly cost-effective. For the most part, the computer technologies supporting computer-based training are adequate. The challenge is to take cost-effective, but maximum advantage of these technologies.

The task force considered simulation, gaming, and training to improve the readiness of joint commanders and staffs. They did not address individual training, nor service-specific collective training. However, they did review the services' collective training conventions and facilities, as well as the available and emerging technological capabilities applicable to joint training, and concluded generally as follows ([39], p. 2):

- Each service and the JCS build their own simulations.
- Redundancy and overlap of simulations are common.
- Separate simulations lack joint training functionality. While simulations typically models service-relevant forces, threats, and operating environment

well, they do not take advantage of other service's efforts, and hence are often inconsistent.

- The simulations do not take advantage of computing and communications technology to have distributed training that avoids wasting resources and time through unnecessary travel.

The task force then made five complementary recommendations: (a) make joint simulations interoperable, (b) promote joint simulation usage, (c) establish requirements for future capabilities, (d) establish a prototype program, and (e) undertake a major joint training initiative. Appendix H, "Actions Required for Implementation," in the task force's report detailed the specific actions to be taken to effect the recommended steps.

There have been isolated cases where parts of these recommendations have been put into effect. For example, relative to previous exercises, the 1990 Return of Forces to Germany (REFORGER) exercises emphasized computer simulation to train higher echelons, and de-emphasized the use of larger numbers of personnel moving realistically (i.e., destructively) over the countryside. This exercise is analyzed in [40]. Unfortunately, the analysis emphasizes narrowly defined, easy-to-measure cost savings (which are small), rather than broadly defined, difficult-to-measure benefits of this sort of training on the performance of higher echelon leaders and managers.

IV. DATA AND ANALYSES

This section reviews OPTEMPO and simulator use in the military services. Previous research on individual and collective training simulation is summarized, and new information is presented. These data are then used to perform cost-effectiveness analyses of the use of simulators in individual and collective training.

A. DATA

The DoD's formal system of military education and training is focused nearly exclusively on individuals within military schools and training institutions or centers. An annual report of such training, the Military Manpower Training Report (MMTR) [1], is submitted to the Congress by the Secretary of Defense (SECDEF) in accordance with 10 U.S.C. 138(d)(2). For 1989, the last year of actual data in the report, approximately 6.7% of the DoD budget, and 14.2% of active military personnel, are receiving, giving, or supporting individual training.[12] However, some individual on-the-job training (OJT) and essentially all collective military-operations training occurs within the services' operational mission units. There is no comprehensive DoD report for collective training similar to that for individual training.

One rough estimate of this training expenditure is operating tempo (OPTEMPO). OPTEMPO costs are justified largely in terms of the collective training that is necessary to gain and maintain satisfactory levels of *force readiness*—the ability of a military force or unit to fight and win in combat. The estimated OPTEMPO in the President's Budget for FY 1991 (prior to the Desert Shield and Desert Storm operations) is shown in Table 2.

Detailed estimates of the associated costs are difficult, but rough estimates of the variable costs of OPTEMPO are possible from budget documents. For example, Table 3 shows estimates for flight OPTEMPO for the three military departments, Table 4, for ship operations and maintenance, and Table 5, for Army vehicle OPTEMPO. The total of $21.4

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12 Active military students, 183.8 thousand; direct military support, 89.2 thousand; BOS and HQ, 30.1 thousand; Total Individual training budget, $19.4 billion [1]. Total DoD budget, $290.8 billion [41]. Total active force, 2,131 thousand [42].

billion from Tables 3 through 5 is useful in that it shows costs that would decrease due to reductions in OPTEMPO.

Table 2. OPTEMPO for Various Services and Systems, FY 1991

Unit and Category	OPTEMPO
Flying Hours Per Crew Per Month	
Army Tactical Helicopter	14.5
Navy/Marine Tactical Air/Antisubmarine Warfare	25.0
Air Force Tactical Air	19.5
Air Force Strategic Air	17.6
Air Force Airlift	30.2
Navy Steaming Days Per Quarter	
Deployed Fleets	50.5
Non-Deployed Fleets	29.0
Army Combat Vehicle Mileage Per Year	800.0

Source: Reference [43].

Table 3. OPTEMPO Costs and Flying Hours for the Services, FY 1991

Category	Cost (Billions of FY 1991 Dollars)	Flying Hours (Millions)
Air Force Total	$6.5	3.4
Peacetime Operating Stocks	2.3	
Industrially Funded Maintenance	2.9	
Aircraft Petroleum, Oil, and Lubricants	1.3	
Navy Total	$4.1	2.2
Aircraft Operations	2.3	
Aircraft Maintenance and Engineering	1.8	
Army Total	$1.1	1.7
Aircraft Petroleum, Oil, and Lubricants	0.1	
Consumables	0.2	
Repair and Depot Maintenance	0.8	
DoD Total	$11.7	7.3

Sources: Costs: Air Force, Reference [44], p. A-32; Navy, Reference [45]; and Army, Reference [46], with an adjustment to Repairables and Depot Spares. Flying hours: Air Force, Reference [44], FY 1989 data; Navy, Reference [8]; and Army, Reference [47].

Table 4. Ship Operations and Maintenance, FY 1991

Category	Cost (Billions of FY 1991 Dollars
Ship Operations	$2.1
Ship Maintenance	$3.4
Ship and Weapon System Maintenance and Engineering	$1.9
Total	$8.4

Source: Reference [45].

Table 5. Army Vehicle OPTEMPO, FY 1991

Category	Cost (Billions of FY 1991 Dollars
Fuel	$0.05
Consumables	$0.30
Repairable Spares	$0.57
Depot Maintenance of Combat Vehicles	$0.37
Total	$1.29

Source: Reference [46], p. 36-43.

Despite the scope of such training implicit in this OPTEMPO, there has been relatively little technology-base research and development (R&D) devoted to it. Most of the training-technology R&D in the Training and Personnel Systems Technology program has traditionally been aimed at the other military training domain—that of individual training in institutions. This has been recognized for at least 15 years, as evidenced by the attention given, and recommendation made for increasing technology-base R&D in support of collective training, by no fewer than four DSB studies [39, 48, 49, and 50].

B. COST-EFFECTIVENESS COMPARISONS

This section reports results from a literature review of simulator costs and effectiveness. The literature reports results for representative flight, maintenance, and collective training simulators. Two preliminary cost-effectiveness comparisons are generated. The first cost-effectiveness comparison shows the trade flying-hour OPTEMPO for possible increases in simulator time. The second compares the costs and effectiveness of SIMNET and field exercises.[13] In addition, we briefly summarize an interesting analysis of the effects of home-station exercises on NTC effectiveness.

The purpose of this review is to highlight key information that is needed to develop cost-effectiveness tradeoffs rather than to present definitive answers. However, based on this preliminary analysis, the key conclusions of this comparison are that each approach (flight simulators versus flying hours, SIMNET versus home-station field exercises) has tasks for which it is much more effective than the others as a training approach, that there are tasks for which both can be used, and that simulators and simulations offer an

13 We hoped to compare costs and effectiveness of NTC and a SIMNET-like facility. It was not possible to obtain comparable effectiveness data. A summary of the cost data collected is included in Appendix A.

opportunity to cost-effectively augment actual equipment or field exercise training. Greater emphasis on simulators, and less on using actual equipment appears to be warranted.

1. Previous Research on Individual and Collective Training—With Simulators

Simulators for individual operators and maintainers have a long history in military training, and have been widely studied. One summary of these studies [16] is itself a summary of both a decade of research at IDA as well as the work of many other authors. A later study surveys more recent analyses [17]. A few of the cost, effectiveness, and cost-effectiveness results cited there are presented below.

a. Simulators in the Training Taxonomy

Simulators are widely used in training. Figure 4 shows examples of where various types of simulators fit within a slightly expanded version of the training taxonomy introduced in Figure 1. Embedded training uses actual equipment being stimulated for the purposes of training. Actual equipment and exercises are increasingly used for training as one moves from the upper left to the lower right of the matrix. Examples of these simulations are discussed below.

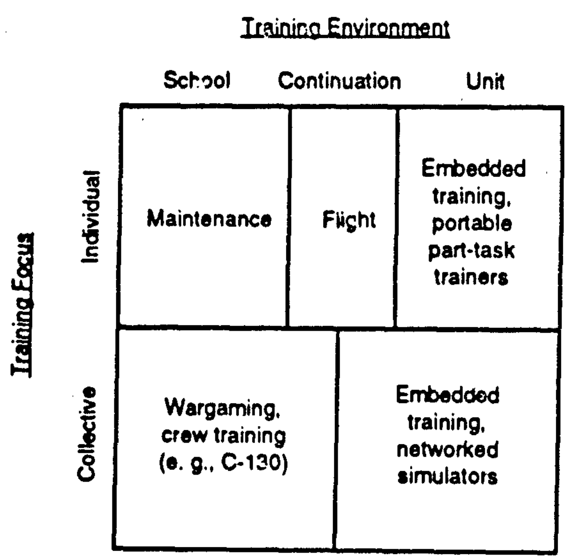

Figure 4. Simulators Placed in the Training Taxonomy

b. Flight Simulators

The investment cost for individual simulators is often similar to the cost of actual equipment. However, Orlansky, Knapp, and String [51] report that the operating and support (O&S) costs for 39 simulators compared with actual aircraft using 1980-81 data was an order of magnitude lower. That is, O&S costs for the median simulator was 8% of O&S costs for actual equipment, and the unweighted mean cost ratio was 11%. The ratios are skewed to the right in that the range was from 2% to 59%, the standard deviation was 0.11, and 34 of the 39 observations are within one standard deviation of the mean.

The life-cycle cost comparisons were not reported in most of these studies. However, fragmentary evidence supported a time to breakeven of one to two years. If we use an O&S cost ratio of 10% and equal procurement prices, discounted life-cycle costs of simulators are as large as 25% of actual equipment costs

Cost ratios for different mixes of simulator and actual equipment training depend on whether there is excess capacity available. If both simulators and actual equipment usage can be increased, the cost ratio would be the O&S cost ratio, 10%. If the choice is between purchasing one or the other, the cost ratio is 25%. If actual equipment is already available but simulators must be purchased, the cost ratio is 33%.

Simulator effectiveness depends on the task being trained. Orlansky and String [52] report the results of a study that compiled 34 Transfer Effectiveness Ratios (TERs) in 22 studies showed a median value TER of 0.41, a mean TER of 0.52, and a standard deviation of 0.45. Comparing these TERs with the cost ratios discussed above, 59% of the TERs were greater than the 0.33 cost ratio, 70% of the TERs were greater than or equal to the 0.25 cost ratio, and 94% were greater than or equal to the 0.1 cost ratio derived above. The size of the TERs was also correlated to characteristics of the task to be trained. Therefore, inferences can be drawn about what tasks should be trained mainly on simulators, and what tasks should be trained mainly on actual equipment.

There is evidence that the marginal contribution of simulator time to the performance of private pilots declines as more of it is used [15]. The results of that report are presented in Table 6. The cumulative hours saved are always based on comparison with the control group (no simulator time). For example, 7 simulator hours save 6.2 flight hours, so the cumulative TER is 0.9. The incremental hours saved in any given row are based on a comparison with the row above it. For example, the incremental savings of 1.6 hour in the 7 simulator hours row indicates that the additional 4 hours of simulator time resulted in 1.6 hour less flying time needed to reach a given level of proficiency. This means that, over that interval, each simulator hour saved 0.4 flight hour; hence, that is the incremental TER. The cost ratio between the simulator and the airplane is 0.57, with the ratio rising to 0.73 if instructor time for both training approaches is included.[14] Therefore, in this example the optimal amount of simulator time is 4-5 hours.

Table 6. Transfer Effectiveness of a Ground-Based General Aviation Trainer

Total Hours		Hours Saved		Transfer Ratios	
Simulator	Flight	Cumulative	Incremental	Cumulative	Incremental
0	44.5				
3	39.9	4.6	4.6	1.5	1.5
7	38.3	6.2	1.6	0.9	0.4
11	37.3	7.2	1.0	0.7	0.2[a]

Source: Reference [15].

Notes: Flight hours are the hours needed to reach a specified level of pilot performance. Hours and transfer ratios to reach final flight check were essentially identical.

[a] Apparent error is due to rounding.

Care should be taken in applying these data to the military because this experiment was done on a low-technology, civilian aircraft and simulator, and small sample sizes in this experiment result in low statistical significance. However, the pattern of the results is consistent with both intuition and the standard concepts of diminishing marginal returns.

The material in [15] also suggests that care be taken in using the TERs reported in [16]. They should be applied with caution if one is considering dramatic changes in the division of time spent on simulators and actual equipment. However, in an era of budgetary stringency, marginal increases in simulator time appear to be cost-effective.

c. Maintenance Simulators

The results reported in [16] for these simulators are not as numerous or reliable as for flight simulators. However, using the criterion of test performance during training, simulators were at least as good as actual equipment (TERs of 1.0), and the investment cost ratios were roughly in the range of 0.5. Using data from other sources [53], O&S costs for maintaining simulators are usually much less than actual equipment.

There are two aspects to the studies summarized here that also tend to bias the results against simulators. First, with respect to cost avoidance, simulators often allowed students to learn faster, resulting in less time in training. The cost savings in pay and

[14] It is not clear from the text whether these ratios are life cycle or only operating costs.

allowances were not usually included in the cost ratios reported in [16] or [17].[15] Second, with respect to the tasks trained, TER comparisons require that training activities be performed on both actual equipment and simulators. One of the strengths of simulators is that they can train tasks that are not trained on actual equipment due to danger or cost. These training advantages are not reflected in the reported TERs.

d. Collective Training Simulators

The Navy has for some years employed computer-based simulations in its fleet operational training facilities in San Diego, California, and at Dam Neck in Virginia Beach, Virginia. These simulations typically involve ships afloat as well as the simulations.

The Air Force's Tactical Air Command has used contract simulation facilities in the aerospace industry for the collective training of three-element teams—two aircraft pilots and a ground-based radar intercept controller or an airborne warning and control system (AWACS)-based controller. The training covers a wide range of tasks, including electronic combat and all-aspect missile defense. For safety, range and environment, coordination, and security reasons this training is not done on actual equipment.

Two different studies of collective training were undertaken using these facilities [54 and 55]. In the first study, the pilots were from Air National Guard and fighter interceptor squadrons. In the second study, the pilots were from active-duty tactical fighter wings. Pre- and post-training surveys were used to determine what tasks needed to be trained, and how the value of existing unit training compared with the simulator training.

Comparisons of perceived training effectiveness for the pilots and controllers are reported in Table 7. For example, in the 1990 study for pilots [54], of the 41 identified tasks, 21 were better trained by the simulator, 8 were equally well trained by the simulator, 6 were better trained in unit training, and 6 were not measured in the simulator. In summary, 71% of all enumerated tasks were trained at least as well in the collective training simulator.

Pilots' opinions on why these results occurred centered around: a) repeated practice within a brief time to try alternative tactics and reinforce positive habits, b) immediate performance feedback in the form of real-time kill removal ([54], p. 19). For controllers, the key element was the ability for immediate after-action reviews with the pilots they were supporting to understand "the content and timing of information required by pilots during

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15 For a further discussion of this point, see Reference [3].

air combat engagements." ([54], p. 23) The subjective opinions expressed in [55] were similar to those from [54], and a correlation of these opinions with pilot characteristics, such as current unit type, qualification, and F-15 flying hours showed no significant relationships.

Table 7. Effectiveness Results for F-15 Multiship/Controller Training

Respondents/ Source	Simulator Better	No Significant Difference	Unit Training Better	Not Measured in Simulator	Totals	Percentage Simulator as Good or Better
Pilots						
[54], p. 15	21	8	6	6	41	71
[55], p. 22[a]	11	15	4		30	87
Controllers						
[54], p. 63-64	34			6	40	85
[55], p. 71	15	5			20	100

[a] Reference [55] presents these data in a way that does not allow this aggregation to be made with certainty. Therefore, to aggregate in this way, all uncertainties were decided favoring continuation training over simulator training.

If it were done on actual equipment, the cost per flying hour for two F-15s is in the range of $10,000, while the simulation facility is available for approximately $1,000 per hour [56].

2. Flying Hours and Flight Simulators

Examining DoD-wide tradeoffs of flying hours and flight simulator use is inherently difficult. The services have peacetime missions that require flying, and this flying does contribute to training. In addition, various aircraft categories and organizations are flying at different proportions of their training requirements, and different aircraft categories are already being trained with different mixtures of actual and simulated equipment. However, budgetary realities encourage a better understanding of the effects of actual and simulated flight on the training of personnel.

A 5% decrease in aircraft OPTEMPO (approximately 365,000 flying hours) would save $585 million. If this money were applied to operating flight simulators, it would increase the number of simulator hours by three to ten times the amount of flight hours given up. TERs seem to support the contention that this reallocation would be cost-effective, but the phenomena of: (a) differential simulator use across services and platforms, and (b) declining incremental training effectiveness suggests that larger changes in OPTEMPO and simulator use be implemented only if the early results of focused experimentation and analysis warrant. Any decrease in aviation OPTEMPO would have to be tailored to the specific types of aircraft involved.

a. Current Simulator Usage and Costs

Our best estimates of simulator usage are as follows. For Army simulator use, operating cost data and manipulation of simulator hour information provided in [38] are shown in Table 8. The simulator hours per month is a rough analog to flying hours per month in the OPTEMPO information cited previously. Imprecision occurs because some simulators have two station cockpits that can be used to train either one crew or two individuals at the same time. Also, these data cover a combination of simulators at Fort Rucker, where simulators are often scheduled for two shifts a day, and simulators at other locations, where such tight scheduling is more difficult. Also shown are FY 1989 operating costs for both simulators and actual equipment.

Table 8. Army Helicopter Simulator Hours and "Per Cockpit" Operating Costs for Simulators and Actual Equipment, FY 1989

	Flight Simulator				
Category	Total Hours (Thousands)	Hours per Month per Seat	Cost per Hour	Actual Equipment Cost per Hour	Simulator Cost Percentage
UH-1 Instrument Flight Trainer	168.8	185	$21	$518	4%
UH-60 Operational Flight Trainer	25.4	132	$123	$1,058	12%
CH-47 Operational Flight Trainer	6.7	121	$229	$1,688	14%
AH-1 Operational Flight Trainer/ Weapons System Simulator	26.1	161	$241	$1,108	22%
AH-64 Combat Mission Simulator	27.0	225	$125	$3,055	4%
Averages	-	164	$148	$1,485	11%

Source: Reference [57].

Note: Total simulator hours is 254,000.

Firm procurement cost data for these simulators is difficult to obtain because estimates depend on the number procured and the level of engineering changes allowed for any given procurement. However, discussion with individuals in the PM TRADE organization [58] support the contention that a full motion simulator with good visual fidelity will cost approximately as much as one copy of the actual equipment.

A rough cost analysis can be done using these data. An AH-64 combat mission simulator costs in the range of $15 million per copy. The O&S costs per cockpit-year are

$0.675 million (5,400 hours times $125 per hour). The undiscounted lifetime cost of the simulator is $25.1 million, and the discounted present value is $20.1 million.

This purchase would be paid for by reducing flying hours. The reduction would depend on the desired budgetary impact. A pay-as-you-go policy would involve giving up 4,910 hours spent in year 1 (4,910 hours at $3,055 per hour yields the $15 million purchase price) and 221 flying hours in years 2 through 16. An alternative is to invest in year 1 and pay back 865 flying hours per year in years 2 through 16.

The cost-effectiveness evaluation would hinge on whether 81,000 additional simulator hours were as effective in training AH-64 pilots as the 8,225 flying hours traded for the simulation time in the pay-as-you-go plan or the 12,975 flying hours traded in the invest now, pay later plan.

A comparison of simulator hours to total flying hours for five different Army helicopters is shown in Table 9. Helicopter type, simulator hours, flying hours, and the proportion of cockpit hours spent in simulators are shown.

Table 9. Comparison of Flying and Simulator Hours for Selected Army Helicopters, FY 1989

Helicopter	Simulator Hours (Thousands)	Flying Hours (Thousands)	Percentage of Cockpit Hours in Simulators
AH-1	26.1	140.7	15.6
AH-64	27.0	69.7	27.9
CH-47	6.7	52.4	11.3
UH-1	168.8	692.1	19.6
UH-60	25.5	191.9	11.7

Sources: Simulator hours, Reference [57]; flying hours, Reference [47] and supporting data.

While detailed data have not yet been published, we have some subjective evaluations of the proporuon of simulator hours to total hours that could be effectively used in Army helicopter training [59]. These are 24-25% for the UH-60, 28-29% for the CH-47, and 31-32% for the AH-1. The fact that the percentages of cockpit hours for these three helicopters shown in Table 9 are lower than the percentages reported by in [58] suggests areas where simulator time could be substituted for flying hours.

For Navy usage, according to Reference [45], 2% of the Primary Mission Readiness activity is contributed by simulators. No simulator contribution is mentioned for Fleet Readiness Squadrons or Fleet Support. We have obtained usage information for Navy simulators, but have not yet analyzed that data. We know where to obtain some Air Force simulator data, but were not able to do so during the course of the study.

b. Increased Simulator Usage—Costs and Cost-Effectiveness

(1) Costs. Constructing equal cost combinations of simulators and actual equipment depends on the mix of simulators that had to be purchased versus those that would be more intensively used. Based on representative costs reported by Orlansky in [16] every flying hour given up releases funds that could be used to increase possible simulator time between 3 and 10 hours over the life cycle. The 3-hour estimate includes simulator acquisition and operation versus actual equipment operation, the latter estimate includes operation only.[16]

Another way to examine this reallocation of funds is through a breakeven analysis. Orlansky reports [16] breakeven points from eight months to two years, which is consistent with the information on the AH-64 combat mission simulator. Therefore, if a given amount of funds were reallocated from flying hours to simulators for a short period of time, later budgets would be able to reduce training expenditure. The effectiveness implications are discussed below.

(2) Cost-Effectiveness. With respect to training effectiveness, the TERs reported in [52] show 59% at or above one-third, and 94% at or above one-tenth. This indicates that, even under the worst case scenario, 59% of these tasks could be cost-effectively trained by increasing simulator usage, and depending on simulator availability, up to 94% of the tasks could be cost-effectively trained by increased simulator usage. The prevalence of TERs that are higher than the ratio of simulator cost to OPTEMPO cost means that equivalent training could be achieved with less money.

c. Large Changes in Simulation

The suggestion to decrease OPTEMPO by 5% and use some of those funds for increased simulator acquisition and operation would result in a large change in the relative usage of simulators and actual equipment. While the 5% decline in OPTEMPO is small, the percentage increase in simulator usage would range between 15% and 50%, depending on how many simulators had to be acquired and how many were already available. The AH-64 example given previously is even more favorable.

Both production theory and empirical work [15] suggest that changes of this magnitude could alter the incremental training transfer effectiveness ratio. Such a change does not refute the contention that more simulator use appears to be cost-effective at this

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16 The AH-64 example shows a range of 6 to 12 even with simulator acquisition included.

time for the current mixture of flying and simulator use. It does counsel against the assertion that large changes in OPTEMPO can be easily offset by still larger changes in simulator use.

3. Comparing a SIMNET-Like Facility with Exercises at Home-Station Range and Maneuver Areas

This section lays out an approach to performing a cost-effectiveness analysis comparing training in a SIMNET-like facility and home-station range and maneuver areas. The data to fully accomplish this comparison are not currently available. However, useful inferences can be drawn from the data that are available. Particularly for the cost data presented below, we believe *a fortiori* arguments can be made. That is, the cost analysis that follows shows that SIMNET is a cost-effective alternative for a subset of tasks currently trained by field exercises. We believe that the cost data presented are biased to underestimate the costs of field exercises, and overestimate the costs of SIMNET. Therefore, SIMNET is actually even more cost-effective. In addition, the missing information suggests areas where further research or recasting of existing data may be valuable.[17]

The results reported here are not inconsistent with the Army's Combined Arms Training Strategy (CATS) [21]. A major goal of CATS is to provide guidance on how training resources can and should be used to produce readiness. The briefing materials that outline this strategy explicitly include training aids, devices, simulators, and simulations as a key part of the overall strategy. They also show examples (e.g., tank crews) where many of the "component parts" of training are mainly provided through training devices and simulations, while overall system competence and battle competence, that is, the integration of all aspects of training, is provided through full service exercises.

a. Costs of Various Options

Costs for home-station field exercises are measured in operating or incremental cost terms, and are basically OPTEMPO costs. The cost for a SIMNET-like facility will include acquisition costs. This is because home-station facilities already exist, but the SIMNET-like facilities have not yet been acquired. Home-station field exercises are estimated from OPTEMPO and ammunition expenditure only, because detailed estimates for costs such as transportation were not easily available to us.

[17] Some NTC cost data are provided in Appendix A.

(1) Cost of a SIMNET-Like Facility. The life-cycle costs of a SIMNET-like facility are shown in Table 10. The explanation for these estimates is provided in Appendix A, and a more detailed time-phasing of these costs is shown in Tables A-1 to A-3. These are roughly correct estimates, not meant to be alternatives to more detailed service estimates, but useful in papers available for unlimited distribution.

Table 10. SIMNET-Like Facility Cost Estimates

Facility	Constant 1991	Current Dollars	Constant 1991, Discounted
CCTT Fixed Site	$900	$1,435.9	$355.2
CCTT Mobile	400	656.5	146.1
AVCATT	900	1,483.4	329.2
Total	$2,200	$3,575.8	$830.5

Notes: For more detail, see Appendix A. CCTT mean Close Combat Tactical Trainer. AVCATT means Aviation Combined Arms Tactical Trainer.

(2) Cost of Field Exercises that Could be Traded for a SIMNET-Like Facility. It is extremely difficult to generate field exercise costs that are meaningfully comparable with SIMNET costs. This is because home-station training facilities vary widely in capability and exercises vary widely in content. However, rough comparisons are reported here.

This cost comparison is between the constant, discounted total life-cycle cost of the fixed-site portion of a SIMNET-like facility and the proportion of OPTEMPO that would be required to "purchase" that SIMNET-like facility, where OPTEMPO is taken as a rough indicator of field exercise activity. The resulting percentage of time can then be compared to subjective or objective estimates of training effectiveness.

Tables A-1 and A-4 to A-6 in Appendix A provide the information necessary to make this comparison. They show that between 8% and 14% of the OPTEMPO or OPTEMPO and training ammunition activity would be forgone in order to release funds that would have the same net present value as those spent on this portion of a SIMNET-like facility. The field exercise mileage forgone in this notional tradeoff (14% of OPTEMPO is approximately 110 miles per vehicle per year) is almost exactly the same as that which is estimated to be savable (as reported in [60]).

b. Effectiveness of Training Options

One of the classic difficulties of a cost-effectiveness analysis is generating quantitative and comparable effectiveness measures for several different options. This problem exists in these data, though there are quantitative pairwise comparisons between SIMNET and home-station training.

(1) Tasks Trained Better by One Method Than Another. Each training option is better at certain aspects of training than are the other options.

- Networked simulator strengths are the ability to exercise standing operating procedures, basic formations, general team building [61], many command and control tasks [21], and the incorporation of opposition forces. Also, networked simulators are particularly useful for timely after-action reviews and ease of task repetition.
- Actual equipment training is superior for dealing with the integration of human vision, particularly of distant indistinct objects, and a sense of motion or orientation into the training exercise [61].

(2) Effectiveness of Exercise and SIMNET Training. There is little quantitative evidence available on the relative effectiveness of these approaches to training, and that which is available is confounded by unfortunate problems with experimental design, missing data values, or small sample sizes. However, the data that are available lead us to believe that, for a significant subset of tasks, SIMNET is more effective than home-station field exercises where equal time is spent in training on the two approaches.

The U.S. Army Armor and Engineering Board executed an experiment where it generated a control and an experimental group of tank platoons, gave them a pre-test to determine their competence, trained the experimental group on SIMNET and the control group through standard field training for six days, and then tested the groups after the training [62]. The groups were scored "Go" or "No Go" on a series of tasks within the given exercises, and the pre- and post-test Go percentages of these scores are shown in Table 11.

Table 11. Performance of Tank Platoons Receiving Standard Field or SIMNET Training

	Percentage of Tasks "Go"	
Type of Training	Pre-Training	Post-Training
Standard Field Training	59	65
SIMNET Training	73	84

Note: This presentation is suggested in Reference [63].

The percentage improvement in Go scores of the SIMNET-trained tank platoons is greater than the field-exercise trained platoons (11% versus 6%), and statistical tests on the differences between the pre- and post-training Go percentages (i.e., comparing 59% and 73% versus 65% and 84%) indicate that the post-training percentages are less likely to be the same.[18] However, the data as shown combine exercise tasks where only a pre-test or only a post-test score was available, and include tasks that were judged not trainable by SIMNET. In addition, these comparisons may be flawed because the post-test differences may be due to the fact that the two groups were not equal before the test.

We reanalyzed the data on which these summary statistics were based, and generated Table 12.[19] In this analysis we took advantage of the fact that there were three kinds of tasks being tested; those that were judged fully, partially, and not trainable by SIMNET. We also removed all data that did not have both a pre- and post-test score. We expected that both SIMNET and field exercises would at least maintain proficiency. The interesting question was whether the SIMNET-trained units would display positive differences compared to the field exercise units.

Table 12. Pre- and Post-Test Percentage "Go" by Training Type and Trainability

Training Type	SIMNET Trainability	Number of Observations	Pre-Test Percentage	Post-Test Percentage
SIMNET	Full	91	58	78[a]
	Partial	30	100	87
	None	26	92	81
Field Training	Full	100	44	47
	Partial	28	86	86
	None	31	81	81

[a] This change is significant at the 0.01 level of confidence. See Appendix B for a more complete explanation.

Only on the tasks that were fully trainable by both SIMNET and field exercises was there a statistically significant difference between pre- and post-test results. As shown in Table 12, the difference was that the experimental (SIMNET) group scored 58% Go pre-test and 78% Go post-test. The decreases in the other SIMNET-trained tasks are not statistically significant, and the changes in all three control (field training) groups were statistically zero.

18 Summary of data in [62], tables 2-2-4 and 2-2-5, p. 2-6; statistical tests reported on p. 2-8.

19 Additional statistical expertise and effort were contributed by Philip M. Lurie of IDA. For a more complete description of the analysis, see Appendix B.

This table indicated that, as a group, the field training units maintained their proficiency, and SIMNET-trained group gained proficiency on the fully trainable items, while their proficiency change on the partially trainable and non-trainable items was not statistically significant. This analysis supports the contention that, for a given subset of tasks that are fully represented in SIMNET, and within a given amount of time, SIMNET training is more effective than field exercises.

In addition, the data indicate that a mix of both types of training has the potential to be the most cost-effective option. If tasks that are fully SIMNET trainable are trained to criteria on SIMNET, there would be more time and resources available to do field training for the other tasks that are not trainable by SIMNET. Results consistent with this sort of specialization are also reported in other analyses of SIMNET-like facilities [61], and in a comparison of pilots who had flight simulator training before Red Flag exercises [64].

One of the main reasons that SIMNET is able to generate better training results is believed to be related to the much greater number of simulated exercises, miles driven, and ordnance fired that can be undertaken in a given period of time with SIMNET as compared to field exercises. For example, in an 11-month period in 1987-88, four M1 tank simulators simulated 18,600 miles of driving [65], which is the average annual mileage for 23 tanks. This means the simulators were able to simulate approximately six times as much driving per time period as the average tank would be driven. In [61], tank platoons traveled approximately 100 miles in three days. Assuming each simulator was used four days a week or 200 days a year, this means each simulator would be "driven" about 7000 miles, or nine times the average annual tank mileage.

(3) Effectiveness of NTC Conditioned on Home-Station Training. One way to measure the marginal effectiveness of home-station training is to use the amount of such training to explain performance as measured in other, more realistic, training exercises. One such analysis done by the Army Research Institute (ARI) is reported in [66] and [67]. In this analysis, the casualty exchange ratio (percentage opposing force (OPFOR) vehicles killed divided by percentage blue force (BLUFOR or friendly) vehicles killed) in NTC exercises was explained by tank mileage driven by the BLUFOR in the six months prior to the exercises, and by a subjective rating of the similarity of the terrain at home station and NTC.

The result of this analysis was that, for defensive missions, home-station mileage was positively related to the casualty exchange ratio, and that a doubling of miles driven increased the exchange ratio by roughly 30% of its value (e.g., if the ratio was 0.5 it would become 0.65).[20]

Comparable analyses of the effectiveness of SIMNET-based training are not available. Once CCTT becomes operational, an analysis that explains the NTC casualty exchange ratio using both home-station tank mileage and CCTT time should allow comparisons of the effectiveness of the two approaches.

(4) Reserve Component Effectiveness. Very few comparisons have been made between the training reserve components currently receive versus the training they would receive with mobile CCTT equipment and occasional access to fixed CCTT equipment. It is our understanding that mobile CCTT equipment would be much more effective than current practice. Failure to consider this additional use leads to understating the value of SIMNET-like facilities.

c. Cost-Effectiveness of SIMNET and Home-Station Training

Some inferences can be drawn from the cost and effectiveness discussions presented here; however, they do not allow definitive answers to cost-effectiveness questions.

The cost data in Table 10, and the effectiveness data reported in Table 12 show that, on the margin, tasks trainable on SIMNET should be trained there. However, as shown in the effectiveness data, SIMNET is not capable of training all the combat-relevant tasks. Tasks not trainable on SIMNET must still be trained at NTC or in other field exercises.

Data cited previously on the marginal effectiveness of simulator-type training [15] indicate that its incremental effectiveness will decline as more of this training is done. If this also applies to SIMNET and home field exercises, it means that even tasks cost-effectively trained at the margin by any one training method cannot necessarily be trained by that method alone. Generating information on the incremental contribution of both individual and networked simulator training would better inform policy makers on the cost-effective mix of training options.

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20 This figure was interpolated from graphical material in [67], the underlying equ‿ion was not reproduced in the citation.

C. SUMMARY

In this paper, we explained how we developed a rough estimate of the cost of OPTEMPO, one of the primary ways collective training is funded during peacetime. In FY 1991 dollars, for DoD, this estimate is $21 billion. Simulations can leverage these expenditures to increase their efficiency and improve readiness and effectiveness.

The Analyses subsection presents two types of cost-effectiveness comparisons: a) the tradeoff of flying-hour OPTEMPO for possible increases in simulator time, and b) a comparison of the costs and effectiveness of SIMNET with actual exercises at field training locations. The quality of the information provided is not sufficient to provide detailed policy guidance, but does appear to offer some preliminary insights.

1. OPTEMPO Versus Flight Simulators

Combining these representative costs found in a review of past studies and a selection of a few current programs suggests that the cost side of a simulator/actual equipment comparison is that flight simulators are 10%-33% of the costs of actual equipment per hour trained. The relative cost of simulators is 10% of actual equipment when both actual equipment and simulators are already in the inventory, the 33% relative cost applies if simulators must be both procured and maintained. With respect to the relative effectiveness of simulators and actual equipment, TER comparisons from the literature suggest that the majority (59%) of tasks trained have TERs greater than 0.33, and 94% have TERs greater than 0.1.

Combining this cost and effectiveness information means that individuals can be cost-effectively trained on simulator–trainable tasks using simulators at current ratios of simulator training to actual equipment training. Additionally, there are tasks that, for safety, environmental, or security reasons, are not currently trained using actual equipment. Many of these tasks can be trained using simulators.

An aggregate comparison of flying OPTEMPO and flight simulator TERs offers the possibility that about 5% of the flying-hour budget could be transferred to simulator acquisition and operation. However, the savings from a 5% decrease in flying hours could be used to generate a 15% to 50% increase in simulator hours (based on the 10% to 33% cost range discussed previously). The effects of those sorts of increases on TERs should be understood before still greater simulator utilization is considered, and we believe experiments should be undertaken to develop this understanding. Existing information on

TERs suggests that equal effectiveness could be maintained without using all of the savings from reduced OPTEMPO to fund additional simulator-based training.

2. SIMNET, NTC, and Home-Station Exercises

We found effectiveness comparisons between SIMNET and home-station field exercises and an analysis of the incremental effect of home-station field exercises on NTC performance. Analysis of an effectiveness comparison between SIMNET and home-station field training supports the hypothesis that SIMNET is extremely effective in increasing performance for SIMNET-trainable tasks relative to standard field training.

Tradeoff analyses were done between vehicle OPTEMPO and networked simulator costs. They showed that investment now in SIMNET-like facilities could be repaid once the facilities were fielded by a decrease of 8%-14% of OPTEMPO. The 14% figure is similar to an Army estimate of the vehicle mileage that would be substituted for by CCTT.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Simulators and training devices are currently used for some individual and crew training of operators and maintainers. Data reported here indicate that more extensive and intensive use of simulators and training devices would be cost-effective. These data also suggest that as more of this sort of training is done, costs and effectiveness outcomes should be monitored to determine how much cost-effectiveness ratios change as a result of the increase in simulator and training device use.

In the past, the vast majority of collective training efforts have been in field exercises and training missions. They still are. More recently, however, advanced technology has been employed to enhance collective training in units through capabilities such as (a) instrumented air combat maneuvering ranges, fleet operational training facilities, and the National Training Center, (b) computer-based models, simulations, and war games, (c) the networking of simulators for training, as in SIMNET, and (d) aircraft simulators and training devices of various complexity.

There has been relatively little R&D devoted to collective training. Unit training (in the sense of the team training of interacting crews, groups, or teams within or between units) has been relatively unexplored in the scholarly literature, even by the service laboratories, though this is precisely the kind of *readiness training* that is central to preparation of military units for combat. As indicated previously, such training does take place within the operational units of the services, but relatively independent of inputs from the training-technology R&D community, and in the absence of consistent, quantitative, and objective evaluation.

With respect to individual and crew simulators, the data and analyses presented in Section IV suggest that relatively small changes in the resources devoted to OPTEMPO, on the order of 5%, could support relatively large changes in simulator usage, in the range of 15% to 50%. Effectiveness data in the literature imply that these resources could be cost-effectively applied to simulator provision to enhance training. Alternatively, some of these resources could be used for simulators and training devices to maintain proficiency while reducing overall training costs. This evidence is strong, but not conclusive, primarily because it is not known how rapidly the incremental effectiveness of simulator training will decline if such training is significantly increased.

With respect to networked simulators, the effectiveness data suggest that SIMNET-like facilities are extremely effective in training a large number of tasks. These SIMNET-like facilities can also be purchased with OPTEMPO reductions in the range of 8% to 14%. They appear to be a good buy. Information that would better support policymaking in this area involves quantifying the interrelationship of the incremental effectiveness of training between SIMNET-like facilities, NTC, and home-station field exercises.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

The purpose of the analyses suggested below would be to supply decision makers with further information on the cost-effectiveness of incremental changes in simulator use.

1. Individual and Crew Simulators

Research is needed to determine the proper balance between simulator-based training and operational training.

The cost-effectiveness of simulations for individual operator and maintainer training has been studied, and there is a body of literature in this area. However, this issue needs additional experimental research for several reasons:

- The cost of simulators is heavily based on digital electronic technology, and the cost of this technology has fallen dramatically and will continue to fall in the future.
- Political and environmental changes of the past few years are likely to further constrain the use of actual equipment and exercises versus current operator and maintainer simulators.
- Previous research has indicated that the marginal impact of simulation on performance can change dramatically depending on the amount of simulator training.
- The proper balance of simulator and operational training is likely to vary substantially by unit type.

These factors suggest that experiments that attempt to gain a better understanding of the contribution of alternative mixes of simulator and operational training to performance would be worthwhile.

2. Networked, Collective Simulators

Quantitative cost-effectiveness studies of networked simulators should be undertaken.

The cost-effectiveness of networked simulators for collective training has not been thoroughly studied. This lack of study is partially because networked simulators are a recent innovation, and partially because it is much more difficult to conceptualize, separate, and measure the incremental effects of alternative training approaches in this context.

One approach to remedying this situation would be to examine the data on performance in NTC and home-station field exercises that have been collected by the Army Research Institute. This could be correlated with prior SIMNET use. The question of interest would be what differential training effectiveness resulted from the SIMNET training. This would allow tasks to be reassigned to training approaches so that, for example, more time would be available during exercises for concentration on tasks that are better trained in that environment.

APPENDIX A

COST ESTIMATE DETAIL

APPENDIX A

COST ESTIMATE DETAIL

This appendix presents details for several cost estimates used in this paper. These include estimates of the Close Combat Tactical Trainer (CCTT) and the Aviation Combined Arms Tactical Trainer (AVCATT) and of potential savings that could arise from less operating tempo (OPTEMPO) and fewer field exercises. Also, cost data for National Training Center (NTC) exercises are provided. Finally, a cost per day of training is calculated for the NTC and a simulator network (SIMNET)-like facility in an effort to compare the two training options.

CCTT AND AVCATT

Current plans for CCTT and AVCATT call for research and development (R&D) for the next several years and production in the late 1990s. For the purposes of estimating cost a fielded life of 15 years is assumed. The CCTT will have fixed and mobile units; the former are mainly for use by active forces, the latter mainly for use by reserve forces.

It is our understanding that detailed cost estimates have not been done for AVCATT, and that CCTT cost estimates are being closely held because of the current stage of the acquisition process. Therefore, the expenditure profiles presented here are based on rough estimates that both the fixed-site portion of CCTT and AVCATT will cost less than $1 billion, that, in constant, undiscounted dollars, the fixed-site portion of CCTT will be 50% operating and support (O&S) and the rest divided between R&D and procurement, and that the mobile CCTT and AVCATT will take advantage of some of the R&D and procurement work done for the fixed-site CCTT, so they will have more than 50% O&S costs.

Tables A-1 through A-3 display time-phased expenditure profiles. They are shown in constant 1991 dollars, in current dollars assuming a 4% inflation rate, and in constant, discounted dollars using a 10% discount rate.

Table A-1. Fixed-Site (Active) CCTT Costs

Year	Cost (Millions) Constant 1991 Dollars	Current Dollars	Constant 1991, Discounted Dollars
1992	$20	$20.8	$18.2
1993	20	21.6	16.5
1994	20	22.5	15.0
1995	20	23.4	13.7
1996	20	24.3	12.4
1997	20	25.3	11.3
1998	165	217.1	84.7
1999	165	225.8	77.0
2000	30	42.7	12.7
2001	30	44.4	11.6
2002	30	46.2	10.5
2003	30	48.0	9.6
2004	30	50.0	8.7
2005	30	52.0	7.9
2006	30	54.0	7.2
2007	30	56.2	6.5
2008	30	58.4	5.9
2009	30	60.8	5.4
2010	30	63.2	4.9
2011	30	65.7	4.5
2012	30	68.4	4.1
2013	30	71.1	3.7
2014	30	73.9	3.4
Totals	$900	$1,435.9	$355.2

Table A-2. Mobile Site (Reserve) CCTT Costs

Year	Cost (Millions) Constant 1991 Dollars	Current Dollars	Constant 1991, Discounted Dollars
1993	5	5.4	4.1
1994	5	5.6	3.8
1995	5	5.8	3.4
1996	5	6.1	3.1
1997	5	6.3	2.8
1998	75	98.7	38.5
1999	70	95.8	32.7
2000	15	21.3	6.4
2001	15	22.2	5.8
2002	15	23.1	5.3
2003	15	24.0	4.8
2004	15	25.0	4.3
2005	15	26.0	3.9
2006	15	27.0	3.6
2007	15	28.1	3.3
2008	15	29.2	3.0
2009	15	30.4	2.7
2010	15	31.6	2.5
2011	15	32.9	2.2
2012	15	34.2	2.0
2013	15	35.5	1.8
2014	15	37.0	1.7
Totals	$400	$656.5	$146.1

Table A-3. AVCATT Costs

Year	Cost (Millions)		
	Constant 1991 Dollars	Current Dollars	Constant 1991, Discounted Dollars
1993	15	16.2	12.4
1994	15	16.9	11.3
1995	15	17.5	10.2
1996	15	18.2	9.3
1997	15	19.0	8.5
1998	145	190.8	74.4
1999	140	191.6	65.3
2000	35	49.8	14.8
2001	35	51.8	13.5
2002	35	53.9	12.3
2003	35	56.0	11.2
2004	35	58.3	10.1
2005	35	60.6	9.2
2006	35	63.0	8.4
2007	35	65.6	7.6
2008	35	68.2	6.9
2009	35	70.9	6.3
2010	35	73.7	5.7
2011	35	76.7	5.2
2012	35	79.8	4.7
2013	35	82.9	4.3
2014	35	86.3	3.9
Totals	$900	$1,483.4	$329.2

DRIVING AND FLYING-HOUR COST TRADEOFFS

In the notional expenditure profiles displayed in the tables, CCTT and AVCATT are in place in the years 2000-2015. Therefore, at that time, driving and flying hours are removed from the OPTEMPO budgets to pay back the investment in CCTT and AVCATT. This payback is set equal to the constant, discounted dollars of the investment. Table A-4 presents the payback for the fixed-site CCTT and the AVCATT in terms of the vehicle and flight OPTEMPO cost.

The question to be addressed is: Where does this money come from? One answer is to take the funds from general OPTEMPO as described in Tables 2, 3, and 5 in the main text. Table A-5 shows the percentage of these budgets that would be needed for both the fixed-site (active) CCTT, and for the AVCATT.

Table A-4. Vehicle and Flight OPTEMPO Cost Tradeoffs

	Cost Tradeoff (Millions)					
	Vehicle OPTEMPO			Flight OPTEMPO		
Year	Constant 1991 Dollars	Current Dollars	Constant 1991, Discounted Dollars	Constant 1991 Dollars	Current Dollars	Constant 1991, Discounted Dollars
2000	$100.1	$142.5	$42.5	$92.8	$132.1	$39.4
2001	100.1	148.2	38.6	92.8	137.3	35.8
2002	100.1	154.1	35.1	92.8	142.8	32.5
2003	100.1	160.3	31.9	92.8	148.6	29.6
2004	100.1	166.7	29.0	92.8	154.5	26.9
2005	100.1	173.4	26.4	92.8	160.7	24.4
2006	100.1	180.3	24.0	92.8	167.1	22.2
2007	100.1	187.5	21.8	92.8	173.8	20.2
2008	100.1	195.0	19.8	92.8	180.7	18.4
2009	100.1	202.8	18.0	92.8	188.0	16.7
2010	100.1	210.9	16.4	92.8	195.5	15.2
2011	100.1	219.4	14.9	92.8	203.3	13.8
2012	100.1	228.1	13.5	92.8	211.4	12.5
2013	100.1	237.3	12.3	92.8	219.9	11.4
2014	100.1	246.7	11.2	92.8	228.7	10.4
Totals	$1,501.7	$2,853.2	$355.2	$1,391.8	$2,644.4	$329.2

Table A-5. Percentages of Vehicle and Flight OPTEMPO Needed for Payback

Label	Vehicle	Flight
Budget (Millions of FY 1991 Dollars)	$1,290	$1,100
Miles/Year or Hours/Month	800 Miles/Year	14.5 Hours/Month
Miles/Year or Hours/Month Saved	62.1 Miles	1.2 Hours
Annual Savings (Millions of FY 1991 Dollars)	$100.1	$92.8
Percentage for Payback	7.8%	8.4%

Another approach is to take these funds from the OPTEMPO and ammunition funds of the units that will make use of the CCTT. Table A-6 shows these costs and the percentage of resources needed, expressed as both costs and miles driven. The costs per hour for the tanks are loaded with a proportional share of the cost per hour of the other vehicles in the tank battalion. Ammunition is assumed to be expended proportional to mileage, and the inclusion of ammunition expenditure is another reason Table A-6 differs from A-5. The results from Tables A-5 and A-6 indicate that the OPTEMPO traded will be 8% to 14%, depending on the base used.

Table A-6. Armored and Mechanized Infantry Payback

Unit Type	Tank Battalion	Mechanized Infantry	Divisional Cavalry	Regimental Cavalry
Dollars/Mile[a]	$166	$87	_[b]	$202
Miles/Year	800	742	_[b]	1241
Number of Vehicles	58	54	_[b]	41
Dollars	$7.7	$3.5	$6.8	$10.3
Ammunition[c]	4.3	1.2	2.1	4.2
Number of Units	34	34	8	6
Total Cost by Unit Type	$410.1	$159.1	$71.1	$87
Total Dollars		$747.1		
Percentage Traded		13.76%		
Dollars/Year		$100.1		
Miles/Year on 800-Mile Base		110.1		

Notes: Algebra not exact due to rounding. All costs are in millions of FY 1991 dollars. This analysis was aided by conversations with Doug Johnson and Lee Paris of U.S. Army TRADOC Analysis Command, White Sands Missile Range, but they bear no responsibility for our use of their information.

[a] Includes apportioned support units obtained primarily from the Training Resource Model (TRM).

[b] Data not provided.

[c] Obtained from the Training Ammunition Management Information System (TAMIS). SRC and unit title used: 17235J430, Tank Battalion (M1A1); 07245L000, Inf BN (Mech); 17395L000, Cavalry Squadron (2ID); 17485L100, Armored Cavalry Squadron, ACR 1X6.

COSTS OF EXERCISES AT NTC

NTC costs will be measured in terms of operating or incremental cost. Each armored battalion and mechanized infantry has the opportunity to use NTC on an approximately 18-month cycle. The visit takes about one month, and half of that time is spent in the actual exercise. The rest of the time is spent packing and unpacking equipment and traveling.

Table A-7 shows the incremental cost of one exercise at NTC. These data are shown in more detail in Tables A-10 to A-12. They have been rounded to the nearest quarter million dollars. A portion of the pay and allowances for the Opposition Force (OPFOR) is included. Although the OPFOR personnel are receiving some training from their participation, the main reason they are there is to provide training for others. Results are provided three ways. Subtotal A would be the incremental costs for one rotation at NTC above the cost of field exercises, assuming that the field exercises had the same amount of driving and ammunition usage. Subtotal B or the total cost can be compared to the cost of a SIMNET-like facility, or to item 6 alone, which is a rough estimate of the cost of a home-station field exercise of similar duration as the NTC exercise. The difference between Subtotal B and the total is OPFOR pay and allowances.

Table A-7. NTC Exercise Costs

Item	Category	Cost Millions
1	Transport, Base to Railhead at NTC	$3.50
2	Transport, Railhead to NTC and Back	1.50
3	Tools and Spares	0.50
4	Range Decontamination	0.25
5	OPFOR OPTEMPO and Ammunition	4.50
	Subtotal A	10.25
6	BLUFOR OPTEMPO and Ammunition	3.00
	Subtotal B	13.25
7	OPFOR Pay and Allowances	3.00
	Total	$16.25

Sources: Dr. Howard McFann, ARI, for items 1,3, and 4; Capt. Dinan (DPTMSEC) for item 2. For item 5, see Table A-11, p. A-9; item 6, Table A-12, p. A-10; item 7, see p. A-10 of this appendix.

COST PER DAY OF TRAINING

The NTC facility offers an average of 10 days of training per battalion per year. The SIMNET facility is being sized for 20 days of training for each person in the battalion for each year. The availability of SIMNET equipment would mean that, for those tasks trainable through SIMNET, units could practice until they got it right, and slow learners would not slow down fast learners. Selective, intensive training such as this would increase overall unit readiness in a way not possible without additional NTCs and more time spent there, and the low variable cost of simulator networks would not be available even with additional NTCs.

Another way to compare these options is to use the cost data to construct a cost per training day per year measure of the cost of training through these various options. This measure simply shows what the present value of one day of training would cost for the entire force. Table A-8 displays this measure and indicates whether the cost is variable or total.

Table A-8. Cost per Training Day per Year

Option	Cost (Millions of Discounted, FY 1991 Dollars)	Variable or Total
NTC with Pay and Allowances	$4.6	Variable
NTC without Pay and Allowances	3.8	Variable
CCTT and AVCTT, 20 days	2.8	Total
CCTT, 20 days	1.7	Total

As previously mentioned, specific reserve component trainers are also being acquired, and reserve units may be able to use the equipment during the times that active units are not using it. The reserve component trainers would be an extra cost and generate additional training. reserve use of the active force CCTT installations would generate little extra cost, but extra benefits. These cost estimates are not included here.

Another approach to understanding these data involve generating relative cost ratios. For example, Table A-9 shows the ratio P_{SIMNET}/P_{NTC} for the various cost and days of training assumptions discussed previously. Using the "CCTT and AVCTT" section of the table, the SIMNET-like facility costs between 60% and 73% of NTC per day of training, using CCTT alone shows 36% to 44% of the cost per day at NTC.

Table A-9. Cost Ratios for SIMNET and NTC Training Options

NTC	CCTT and AVCTT (20 Days)	CCTT (20 Days)
Without Pay and Allowances	0.73	0.44
With Pay and Allowances	0.60	0.36

Note: The costs used are the variable cost of NTC and the total cost of a SIMNET-like facility.

These cost figures are biased against SIMNET-like facilities in several ways. As mentioned previously, training of reserve component at these sites is ignored. The CCTT costs include installations in Europe and Korea, but the Combined Arms Training Centers in those areas are not counted in the costs of NTC. In addition, the opportunity cost of the land on which NTC and home-station training take place is not included. This is probably not significant for NTC itself, but is clearly becoming more important for other training and exercise areas (see Reference [8]), and would be a large part of the cost of another NTC.

NTC COSTS FOR COMPARISON WITH SIMNET-LIKE FACILITY

Table A-10 shows the Subtotal B and total from Table A-7 annualized and displayed in current and constant 1991, discounted dollars for the years 2000-2015.

INCREMENTAL OPTEMPO COSTS FOR NTC VEHICLES

Most of the incremental costs for NTC, along with their sources, are listed in Table A-7. The details of the OPTEMPO cost estimate for OPFOR are shown in Table A-11. The M551 (Sheridan) masquerades as an OPFOR vehicle.

Table A-10. NTC Costs with and without OPFOR Pay

	Cost (Millions)					
	NTC Costs without OPFOR Pay			NTC Costs with OPFOR Pay		
Year	Constant 1991	Current Dollars	Constant 1991, Discounted	Constant 1991	Current Dollars	Constant 1991, Discounted
2000	$159.0	$226.3	$67.4	$195.0	$277.5	$82.7
2001	159.0	235.4	61.3	195.0	288.6	75.2
2002	159.0	244.8	55.7	195.0	300.2	68.3
2003	159.0	254.6	50.7	195.0	312.2	62.1
2004	159.0	264.7	46.1	195.0	324.7	56.5
2005	159.0	275.3	41.9	195.0	337.7	51.3
2006	159.0	286.4	38.1	195.0	351.2	46.7
2007	159.0	297.8	34.6	195.0	365.2	42.4
2008	159.0	309.7	31.5	195.0	379.8	38.6
2009	159.0	322.1	28.6	195.0	395.0	35.1
2010	159.0	335.0	26.0	195.0	410.8	31.9
2011	159.0	348.4	23.6	195.0	427.3	29.0
2012	159.0	362.3	21.5	195.0	444.4	26.4
2013	159.0	376.8	19.5	195.0	462.1	24.0
2014	159.0	391.9	17.8	195.0	480.6	21.8
Totals	$2,385.0	$4,531.5	$564.2	$2,925.0	$5,557.5	$691.9

Table A-11. OPFOR OPTEMPO and Ammunition Cost

Unit Type	OPFOR
Dollars per Mile[a]	$82
Miles per Year[b]	3,200
Number of Vehicles[c]	193
Annual Expenditure	$50.6
Monthly OPTEMPO Expenditure	$4.22
Monthly Ammunition Expenditure	$0.27
Total Monthly Expenditure	$4.49

Note: Except for dollars per mile, all costs are in millions of FY 1991 dollars.

[a] Army Average OPTEMPO for M551.

[b] Reference [67] shows approximately 4,000 miles per year, but 800 would occur regardless.

[c] According to Major Centrick, DSOPS Training, the number fluctuates between 193 and 198.

INCREMENTAL BLUFOR COSTS FOR NTC EXERCISES

Table A-12 shows the monthly OPTEMPO costs for the blue force (BLUFOR or friendly forces) OPTEMPO costs. With the exception of mileage driven, it recasts information from Table A-6 in the form used for Table A-11. Mileage driven is based partially on a monthly average annual OPTEMPO mileage, e.g., 800 miles for tank battalions. In addition, because time at NTC is the culmination of a great deal of effort, we believe that commanders will save OPTEMPO budget in order to expend it at NTC. Therefore, we assume that mileage will accrue at a rate 50% higher than average, e.g., 1,200 miles per year for tank battalions.

Table A-12. BLUFOR OPTEMPO and Ammunition Costs

Unit Type	Tank Battalion	Mechanized Infantry
Dollars per Mile	$166	$87
Miles per Year	1,200	1,113
Number of Vehicles	58	54
Annual Expenditure	$11.6	$5.3
Monthly Expenditure	$0.965	$0.438
Total Monthly OPTEMPO Expenditure	$1.403	
Total Monthly Ammunition Expenditure	1.684	
Total Monthly Expenditure	$3.087	

Notes: Except for dollars per mile, all costs are in millions of FY 1991 dollars. Cost per hour and number of vehicles from Table A-6, miles per year from estimate in text, ammunition usage from Training Ammunition Manager (AFZJ-PTT) NTC, Fort Irwin.

OPFOR MANPOWER COSTS

The assumptions made and calculations used for OPFOR manpower costs are explained here. The combat strength of the OPFOR is 2,050, consisting of 1,600 permanently assigned personnel and 450 augmentees (330 infantry and 120 engineers). We assumed that augmentee participation is training; hence, they are not counted in the cost estimate. We further assumed that the permanently assigned OPFOR is receiving training as well, but far more training than it otherwise would. Therefore, the cost estimate is decremented by 25%. A value of $30 thousand per year per person is used as the average annual pay and allowances. This results in $3 million per month in OPFOR personnel costs allocated against NTC ($30,00th × 1,600 personnel = $48,000,000 per year; $48,000,000 × 0.75 = $36,000,000 per year; $36,000,000 + 12 months = $3,000,000 per month).

APPENDIX B

STATISTICAL DATA AND ANALYSIS

APPENDIX B
STATISTICAL DATA AND ANALYSIS

This appendix summarizes the data that compare the effects of SIMNET and field exercises training on the performance of specific field exercises. It then describes the statistical test used and presents the results of those tests.

DATA

The data came from Gound and Schwab [62]. The U.S. Army Armor and Engineering Board generated a control group and an experimental group of tank platoons, gave them a pre-test to determine their competence, trained the experimental group on SIMNET and the control group through standard field training, and then tested the groups after the training. The exercises used were taken from the Army Training and Evaluation Program 17-237-10 Mission Training Plan (coordinating draft) situation training exercises (STX). The exercises chosen were B (Hasty/Deliberate Defense), E (Movement to Combat), and F (Hasty Attack). Individual tasks within each exercise were rated on whether they were fully, partially, or not trainable on SIMNET.

The groups were scored "Go" or "No Go" on the tasks within the given exercises. One summarization of these results is presented in Table 11 in the main text. That summarization reveals a problem with the design of the experiment, but hides one way to analyze the data that reveals additional information.

The problem with the experiment is that the SIMNET-trained units were more capable at the start of the test. Therefore, it is possible that the differential results from SIMNET and home-station exercises are a product of characteristics of the units rather than of the training. In addition, these percentages include tasks that were scored only pre-training or only post-training.

These data were reanalyzed at IDA.[1] In this analysis, we took advantage of the fact that the data identified three kinds of tasks being tested; those that were judged fully, partially, and not trainable by SIMNET. We also removed all data that did not have both a

1 Additional statistical expertise and effort were contributed by Philip M. Lurie of IDA.

pre- and post-test score. These data are summarized in the contingency tables shown in Table B-1. Each of the six sub-tables represents data from either the experimental (SIMNET) or control (field exercise) group, on tasks that are either fully, partially, or not trainable by SIMNET.

Table B-1. Contingency Tables for Field Exercise and SIMNET Training

	Fully Trainable				Partially Trainable				Not Trainable			
	Go	No Go	Total	%	Go	No Go	Total	Percent	Go	No Go	Total	%
SIMNET												
Go	47	6	53	58	26	4	30	100	20	4	24	92
No Go	25	13	38	42	0	0	0	0	1	1	2	8
Total	72	19	91		26	4	30		21	5	26	
Percent	78	22			87	13			81	19		
Field Excerise												
Go	26	18	44	44	22	2	24	86	21	4	25	81
No Go	21	35	56	56	2	2	4	14	4	2	6	19
Total	47	53	100		24	4	28		25	6	31	
Percent	47	53			86	14			81	19		

For each of the six combinations, a sub-table shows a cross-tabulation of the pre- and post-test score on the tasks within the individual exercises. The table should be read as follows. Using the data for the experimental (SIMNET) units on tasks that were judged to be fully trainable on SIMNET, there were 91 observations on a particular task for a particular platoon that had a pre- and post-test grade. Of those observations, 47 were Go both before and after the test, 25 were No Go before the test and Go after the SIMNET training, 13 were No Go both before and after the training, and 6 were Go before the training, and No Go afterward. One way of viewing these data is that 58% of the pre-training scores were Go, and 78% of the post-training scores were Go. Another way is that 6 of the 53 pre-training Gos became No Gos, while 25 of the 38 pre-training No Gos became Gos.

The questions are whether both types of training at least maintain competence, and whether the SIMNET training is better than field training at maintaining or improving competence.

STATISTICAL TEST

Two generalizations of each of the sub-tables in Table B-1 are shown in Table B-2. In Table B-2, a, b, c, d, and n are the observed cell frequencies, and pa, pb, pc, and pd are the probabilities derived by dividing the observed frequencies by the total sample, n.

Table B-2. Generalized Contingency Tables

	Frequencies			Probabilities		
	Go	No Go	Total	Go	No Go	Total
Go	a	b	a + b	pa	pb	pa + pb
No Go	c	d	c + d	pc	pd	pc + pd
Total	a + c	b + d	n	pa + pc	pb + pd	1

The null hypothesis to be tested is the probability that pb = pc. The alternative hypothesis is that pb ≠ pc. If the null hypothesis is accepted, the training has had no significant effect on performance. If the alternative hypothesis is accepted, the training has had a significant effect on performance. If the alternative hypothesis is accepted, and pc > pb, then the training has been helpful.

The test to be used is called McNemar's test (for descriptions of this test, see References [68], p. 72-77, or [69], p. 257-261). The test statistic is:

$$\chi^2 = \frac{(|b-c| - 1)^2}{(b+c)}$$

distributed chi square with one degree of freedom. The critical values for confidence levels 0.90, 0.95, and 0.99 are 2.71, 3.84. and 6.63, respectively. The calculated results are shown in Table B-3. As can be seen from the table, SIMNET training on tasks that were judged fully trainable by SIMNET significantly improved post-training performance. None of the other effects were significantly different from zero. While the initial difference in the experimental and control group suggest caution, this finding is consistent with SIMNET being a relatively effective training method.

Table B-3. Calculated Test Statistic Values

	Fully Trainable	Partially Trainable	Not Trainable
SIMNET	10.45	2.25	0.80
Field Trained	0.10	0.25	0.13

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ABBREVIATIONS

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ADST	Advanced Distributed Simulation Technology
ASD(FM&P)	Assistant Secretary of Defense (Force Management and Personnel)
AVCATT	Aviation Combined Arms Tactical Trainer
CATS	Combined Arms Training Strategy
CCTT	Close Combat Tactical Trainer
CGTU	crew, group, team, or unit
CINC	commander-in-chief
CONUS	continental United States
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DSB	Defense Science Board
GAO	Government Accounting Office
IDA	Institute for Defense Analyses
MOE	measure of effectiveness
NTC	National Training Center
O&S	operating and support
OASD(FM&P)	Office of the Assistant Secretary of Defense (Force Management and Personnel)
OJT	on-the-job training
OPFOR	Opposition Force
OPTEMPO	operating tempo
OSD	Office of the Secretary of Defense
PM TRADE	Project Manager, Training Devices
R&D	research and development
RDT&E	research, development, test and evaluation
SECDEF	Secretary of Defense
SIMNET	simulator networking
SOF-ATS	Special Operations Forces-Air Training System
STX	situation training exercises
TER	Transfer Effectiveness Ratio
TRADOC	Training Doctrine and Command

USAF	United States Air Force
USAREUR	United States Army locations in Europe
USN	United States Navy

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